ROBERT BOYLE AND THE SIGNIFICANCE OF SKILL AND EXPERIENCE IN SEVENTEENTH-CENTURY NATURAL PHILOSOPHY

Gary V. Chipman, B.A.

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APPROVED:

Marilyn Morris, Major Professor
Laura Stern, Committee Member
Harold Tanner, Committee Member
Richard Lowe, Chair of Graduate Studies in History
Richard Golden, Chair of the Department of History
C. Neal Tate, Dean of the Robert B. Toulouse School of Graduate Studies

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The purpose of this study is to examine how English natural philosophers of the seventeenth century—in particular, Robert Boyle (1627–1691)—considered and assessed the personal traits of skill and experience and the significance of these characteristics to the practice of seventeenth-century science. Boyle's writings reveal that skill and experience impacted various aspects of his seventeenth-century experimental natural philosophy, including the credibility assessment of tradesmen and eyewitnesses to natural phenomena, the contingencies involved in the making of experiments, and Boyle's statements about the requisite skills of experimental philosophy in contrast to other traditions. Subtopics explored include the popularization of science and Boyle's expectations concerning the future improvement of natural philosophy.

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ABBREVIATIONS

Citations within footnotes include the following abbreviations for titles of works by Robert Boyle contained within *Works* (below). I have also included years of original publication.

The Works of the Honourable Robert Boyle, ed. Thomas Birch, 3rd edition, 6 vols. (Hildesheim, Germany: Georg Olms, 1965).

Christian Virtuoso, I	*The Christian Virtuoso: Shewing That by Being Addicted to Experimental Philosophy a Man is Rather Assisted Than Indisposed to be a Good Christian* (1690)
Christian Virtuoso, I, Appendix	*Appendix* to *The Christian Virtuoso* (ed. Henry Miles, first published in Birch's 1744 edition)
Christian Virtuoso, II	*The Christian Virtuoso. The Second Part* (ed. Henry Miles, first published in Birch's 1744 edition)
Cold	*New Experiments and Observations Touching Cold, or an Experimental History of Cold, Begun* (1665)
Colours	*Experiments and Considerations Touching Colours* (1664)
Certain Physiological Essays	*Certain Physiological Essays, and Other Tracts Written at Distant Times, and on Several Occasions* (1661; 2nd ed., 1669)
Defence	*A Defence of the Doctrine Touching the Spring and Weight of the Air* (1662)
Examen	*An Examen of Mr. T. Hobbes's* Dialogus Physicus de Naturâ Aëris (1662)
Exp. Obs. Physicae	*Experimenta & Observationes Physicae: Wherein are Briefly Treated of Several*

	Subjects Relating to Natural Philosophy in an Experimental Way (1691)
Forms and Qualities	*The Origin of Forms and Qualities According to the Corpuscular Philosophy, Illustrated by Considerations and Experiments* (1666)
Gems	*An Essay About the Origin and Virtues of Gems* (1672)
Hidden Qualities of Air	*Tracts: Containing Suspicions about Some Hidden Qualities of the Air* (1674)
High Veneration	*Of the High Veneration Man's Intellect Owes to God; Peculiar for his Wisdom and Power* (1685)
History of Air	*The General History of the Air: Designed and Begun by the Honourable Robert Boyle* (1692)
Hydrostatical Paradoxes	*Hydrostatical Paradoxes: Made Out by New Experiments For the Most Part Physical and Easy* (1666)
Mechanical Origin of Qualities	*Experiments, Notes, &c. about the Mechanical Origin or Production of Divers Particular Qualities* (1675)
Medicinal Experiments	*Medicinal Experiments: Or a Collection Of Choice and Safe Remedies, for the Most Part Simple, and Easily Prepared* (1692-94)
Occasional Reflections	*Occasional Reflections Upon Several Subjects, Whereto is Premised a Discourse about Such Kind of Thoughts* (1665)
Reason and Religion	*Some Considerations about the Reconcileableness of Reason and Religion* (1675)
Sceptical Chymist	*The Sceptical Chymist; or Chymico-Physical Doubts & Paradoxes* (1691)

Specific Medicines	*Of the Reconcileableness of Specifick Medicines to the Corpuscular Philosophy* (1685)
Spring	*New Experiments Physico-Mechanical, Touching the Spring of the Air and its Effects* (1660)
Spring, 1st Continuation	*A Continuation of New Experiments Physico-Mechanical, Touching the Spring and Weight of the Air, and their Effects. The First Part* (1669)
Spring, 2nd Continuation	*A Continuation of New Experiments Physico-Mechanical, Touching the Spring and Weight of the Air, and their Effects. The Second Part* (English Trans., 1682)
Things Above Reason	*A Discourse of Things Above Reason: Inquiring Whether a Philosopher Should Admit There Are Any Such* (1681)
Usefulness, I	*Some Considerations Touching the Usefulness of Experimental Natural Philosophy. The First Part* (1663)
Usefulness, II, sect. 1	*Some Considerations of the Usefulness of Natural Philosophy. The Second Part. The First Section. Of Its Usefulness to Physick* (1663)
Usefulness, II, sect. 2	*Some Considerations Touching the Usefulness of Experimental Natural Philosophy. The Second Tome, Containing the later Section of the Second Part* (1671)

INTRODUCTION

When scholars approach twentieth-century research dedicated to the emerging experimental science of seventeenth-century England, they often separate approaches into generalized categories. Scholars talk most broadly of "internalist" and "externalist" interpretations. That is, those who see the developments in seventeenth-century science as examples of individual inspiration within a context of intellectual traditions comprise the internalist camp; on the other hand, externalists are so labeled for emphasizing the social, political, and religious motivations for the promoters of the "new science."[1] Although it is something of an imperfect categorization, much of Michael Hunter's work resides generally within the internalist camp. His *Science and the Shape of Orthodoxy* and his *Science and Society in Seventeenth-Century England* elaborate social and political currents, but overall he stresses the idiosyncrasies of individuals within larger intellectual frameworks, such as Aristotelianism, astrology, and alchemy.[2] A revealing

[1] H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Chicago and London: University of Chicago Press, 1994), chapters 4 and 5. Cohen's thorough study analyzes the scholarship addressing the Scientific Revolution throughout Europe, not just in England. He traces the "internal route," as well as "external" theses asserting religious, social, and economic causes for the emergence of Western science. For a more concise discussion of internal and external approaches applied to English science, see John Henry, "The Scientific Revolution in England," in *The Scientific Revolution in National Context,* eds. Roy Porter and Mikulas Teich (Cambridge: Cambridge University Press, 1992), 178–182. Also see Michael Hunter, "The Conscience of Robert Boyle: Functionalism, 'Dysfunctionalism,' and the Task of Historical Understanding," in *Renaissance and Revolution: Humanists, Scholars, Craftsmen, and Natural Philosophers in Early Modern Europe,* eds. J. V. Field and Frank A. J. L. James (Cambridge: Cambridge University Press, 1993), 147–148.

[2] Michael Hunter, *Science and the Shape of Orthodoxy: Intellectual Change In Late Seventeenth-Century Britain* (Woodbridge, England: Boydell Press, 1995); Michael Hunter, *Science and Society in Restoration England* (Cambridge: Cambridge University Press, 1981). See also, introduction to *Robert Boyle Reconsidered*, ed. Michael Hunter (Cambridge: Cambridge University Press, 1994).

contrast emerged in the 1980s and early 1990s between the work of Hunter and both Margaret Jacob and J. R. Jacob. In an externalist vein, Jacob and Jacob connect the reasons behind opposing philosophical commitments to the competing social, political, and religious allegiances that emerged from the Interregnum period.[3] For example, Margaret Jacob represents the emerging experimental natural philosophy as a deliberate weapon that Latitudinarians used to protect their "social and political" interests against radicals and atheists.[4] Steven Shapin and Simon Schaffer elaborate a modified externalist view with a slightly different focus. They claim that larger societal and political issues of the Restoration influenced disputes between the Royal Society and its critics—namely Thomas Hobbes—during the creation of the Society's experimental program.[5] Within the vast amount of scholarly attention that Shapin and Schaffer have drawn, many scholars have leveled criticism at their presumption of a Royal Society unanimity that matched experimentalism with political conservatism.[6] Roy Porter asserts an even more generalized external focus to the history of science by emphasizing how national context imparted a unique flavor to the science of separate European nations.[7] Perhaps the wisest

[3] Margaret C. Jacob, *The Newtonians and the English Revolution, 1689-1720* (Ithaca, N.Y.: Cornell University Press, 1976); Margaret C. Jacob, *The Radical Enlightenment: Pantheists, Freemasons, and Republicans* (London: George Allen, 1981); J. R. Jacob, *Robert Boyle and the English Revolution: A Study in Social and Intellectual Change* (New York: Burt Franklin, 1977).
[4] M. Jacob, *The Newtonians,* 17–18.
[5] Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Way of Life* (Princeton, New Jersey: Princeton University Press, 1985).
[6] Malcolm Oster, "Virtue Providence and Political Neutralism: Boyle and Interregnum Politics," in *Robert Boyle Reconsidered,* ed. Michael Hunter (Cambridge: Cambridge University Press), 19–32; Rose-Mary Sargent, "Learning From Experience: Boyle's Construction of an Experiemtnal Philosophy," in *Robert Boyle Reconsidered*, 57–74; Hunter, introduction to *Robert Boyle Reconsidered*, 1–16.
[7] Roy Porter and Mikulás Teich, eds., introduction to *The Scientific Revolution in National Context* (Cambridge: Cambridge University Press, 1992), 1–11.

approach to internal and external distinctions is, as John Henry suggests, to let these labels remain as historiographical descriptors rather than philosophical assertions.[8]

Nevertheless, these larger interpretations resonate throughout certain recurring topics within the history of seventeenth-century English science. Recognition of an emerging probabilistic form of knowledge during the seventeenth century has brought the topic of credibility (of witnesses to matters of fact) into the scholarship. Barbara Shapiro and Steven Shapin each apply a different perspective while explaining how seventeenth-century thinkers assessed the testimony of witnesses to natural phenomena.[9] Shapiro describes credibility and probability in the context of mutual intellectual exchange among various fields of study. Shapin recognizes the same probabilistic constructs but situates credibility within the context of English gentlemanly culture. In addition to credibility issues, modern scholars apply different interpretations to the manner in which experimental science developed in late seventeenth-century England. Steven Shapin and others assert the transplantation of social conventions, such as gentlemanly decorum, into experimental procedures.[10] Rose-Mary Sargent, on the other hand, emphasizes the importance of unforeseen practical contingencies involved in the pursuit of experiments and thus presents a more trial-and-error development.[11] In addition, speculation about varying levels of popularity for the new experimental philosophy are prevalent. Michael

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[8] John Henry, "Scientific Revolution in England," 181.
[9] Barbara Shapiro, *"Beyond Reasonable Doubt" and "Probable Cause": Historical Perspectives on the Anglo-American Law of Evidence* (Berkeley, Cal.: University of California Press, 1991); Barabara Shapiro, *Probability and Certainty in Seventeenth-Century England: A Study of the Relationships Between Natural Science, Religion, History, Law, and Literature* (Princeton, New Jersey: Princeton University Press, 1983); Shapin and Schaffer, *Leviathan and the Air-pump*; Steven Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England* (Chicago and London: University of Chicago Press, 1994).
[10] Steven Shapin, "The House of Experiment in Seventeenth-Century England," *Isis* 79 (1988): 373–404. Shapin, *Social History of Truth*.

Hunter's study about the composition of the Royal Society's members during the 1660s and 70s reveals that the aristocratic and gentlemanly elite comprised the membership, despite the group's claims of broad participation.[12] In this vein of societal attitudes toward experimental labor, Stephen Pumphrey analyzes apprehensions about experimental labor during the late seventeenth and early eighteenth centuries.[13] He claims that (1) a middling sort did the majority of the work for which the gentlemen Fellows of the Royal Society took the credit and (2) residual attitudes toward manual labor prevented this active middling sort from achieving gentlemanly philosophical status of other members. Steven Shapin and Simon Schaffer have also approached both gentlemanly participation in science and feelings about experimental work among members of high social standing.[14] Finally, perhaps the most commonly recurring subject concerns the relationship between "new science"—an approach that was experimental, mathematical, and mechanical in its conceptionalization—and other philosophical approaches, such as Aristotelianism or (al)chemical traditions. Much of the scholarly attention given to this interaction focuses on divergent theoretical outlooks and conflicting methods for knowledge-gathering.

The purpose of this study is to reveal an under-served theme from late seventeenth-century science that bears significantly upon the above-mentioned topics: the ways in which English natural philosophers thought about the personal traits of skill and

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[11] Sargent, "Learning from Experiment."
[12] Michael Hunter, *The Royal Society and Its Fellows, 1660–1700: The Morphology of an Early Scientific Institution* (Bucks, England: British Society for the History of Science, 1982).
[13] Stephen Pumphrey, "Who Did the Work? Experimental Philosophers and Public Demonstrators in Augustan England," *British Journal of the History of Science* 28, no. 27 (June 1995): 131–156.
[14] Shapin and Schaffer, *Leviathan and the Air-Pump*; Shapin, "House of Experiment."

experience and how consideration of these qualities influenced knowledge-making. I focus upon the writings of Robert Boyle (1627–1691), whose prolific experimental tracts and prodigious character served proponents of the "new science" as models for proper philosophical practice. Skill and experience exist as occasional themes in twentieth-century scholarship. Shapin and Schaffer, for example, implicitly broach the subject of skill while exploring the significance of opposing views about ingenuity and mechanical contrivances in the debate between Thomas Hobbes (1588–1679) and Robert Boyle during the 1660s.[15] Separately, Shapin elaborates what he perceives as a seventeenth-century contrast between the concepts of skill and experience and gentlemanly knowledgeability.[16] However, an analysis of a variety of Boyle's works reveals the significance of the concepts *skill* and *experience* on many different levels: the credibility assessment of witnesses to natural phenomena and experiments, the contingencies involved in the making of experiments and an experimental program, and statements about the proper skills of the experimental natural philosophy in contrast to other traditions. These topics comprise the chapters of this study. Examining Boyle's consideration of these human characteristics also illuminates important ancillary subjects—the popularization of English experimental science, alchemy, religion, and the future improvement of science and society—significant to the scholarship dedicated to Boyle and seventeenth-century science. The qualities of skill and experience have relevance for scholarship addressing seventeenth-century science. Because the brand of

[15] Shapin and Schaffer, *Leviathan and the Air-Pump,* 129–131.
[16] Shapin, *Social History of Truth,* chapter 8. Also, Robert Iliffe traces Robert Hooke's socially interactive pursuit of manipulative skill through different sites in London among which useful intelligence flowed. See Robert Iliffe, "Material Doubts: Hooke, Artisan Culture, and the Exchange of Information in 1670s

experiment that Robert Boyle and other Fellows of the Royal Society propagated involved work, it revealed the varying levels of human skill and practical knowledge that surrounded their activity.

Understanding about the significance of these concepts to research in the field emerges further when one considers the complex intellectual and social backdrop in which they had relevance. Most English scientists of the late seventeenth century labored toward a common task of reforming and extending knowledge, though often disagreeing on the best means. Of course, many virtuosi heralded the inductive empiricism of Francis Bacon (1561–1626) as the cornerstone of the emerging experimental natural philosophy of the mid and late century. In practice, however, most virtuosi of the day combined an expressed devotion to Baconian empirical principles with a variety of philosophical systems and worldviews. Combined with the mechanical natural philosophy that has become the signifying characteristic of the seventeenth century, vitalistic theories that imbued nature with animated forces still persisted. Similarly, intellectuals such as Henry More (1614–1687) and Ralph Cudworth (1617–1688) espoused Platonic and Neoplatonic theories. In addition, the chemical philosophy of Paracelsus (1493–1541), along with a lingering Hermetic tradition, remained strong among English devotees. Still many others committed to the new science saw nothing inconsistent about a continued commitment to "occult" pursuits like astrology and alchemy.[17]

London." *British Journal for the History of Science* 28 (September 1995): 285–318.

[17] For example, in recent years scholars have lavished attention on Robert Boyle's alchemical interests, including his (now) established belief in and efforts towards the transmutation of metals. See, Lawrence Principe, *The Aspiring Adept: Robert Boyle and His Alchemical Quest, Including Boyle's "Lost"* Dialogue on the Transmutation of Metals (Princeton, New Jersey: Princeton University Press, 1998); Michael Hunter, "Alchemy, Magic and Moralism in the Thought of Robert Boyle," *British Journal of the History of Science* 23, no. 79 (December 1990): 387–410; Lawrence Principe, "Boyle's Alchemical Pursuits," in

This complex and only-seemingly incongruent collection of methodologies and world systems is now a well-established phenomenon necessary for understanding seventeenth-century England and Europe.[18] Nonetheless, for those committed to the emerging experimental philosophy in England, Baconianism was the slogan. This found expression in 1660 with the creation of a formal institution committed to experimental science, the Royal Society. Though it is wrong to search for a single Society orthodoxy, Thomas Sprat (1635–1713), Joseph Glanvill (1636–1680), and others who propagandized the ideals of the new institution, expressed a devotion to corporate experiment and record keeping, important components of the Baconian program.[19] Also essential to the Baconian production of science was an emphasis on direct sensory experience and observation, practices that the virtuosi of the Royal Society espoused. Yet, in a thorough examination of the Society's minutes during the 1660s and 70s, Michael Hunter describes a "steady decline in corporate experimental trials" during this time. Instead, he finds an increasing number of reports about activities done by its members *outside* the confines of the Society.[20] Although a great deal of organized work still persisted and the Society developed a respected reputation in England and abroad, a majority of the Society's participants did "most of their science on their own."[21] This dispersion of scientific activity necessitated many ancillary practices, not the least of which was organized

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Robert Boyle Reconsidered, 91–102.

[18] Michael Hunter ambitiously attempts to redirect descriptions of the period that emphasize polarizations of the these various worldviews in *Hunter, Science and the Shape of Orthodoxy.* Hunter deals with alternative intellectual traditions cumulatively by describing their coexistence in the thought and work of individuals, such as Elias Ashmole, Christopher Wren, John Evelyn, and others.

[19] Hunter, *Science and Society*, 47, 37–38; Shapin and Schaffer, *Leviathan and the Air-Pump*, 55-59.

[20] Hunter, *Science and Society*, 42.

[21] Ibid., 46.

correspondence among virtuosi, achieved originally and brilliantly by Henry Oldenburg (1618?–1677), the German émigré who served as the Royal Society's first secretary.[22]

In practice, this experimental community grew even further beyond those virtuosi who participated in and benefited from this network of correspondence. The pursuit of experimental natural philosophy during the late seventeenth century in England necessitated a vast number of contacts, both formal and informal, as a natural philosopher gained knowledge through direct experience or from literature, correspondence, and word-of-mouth. This broad cast of relevant actors, both on-stage and in the wings, constituted the backdrop for the issues upon which I focus. To obtain scientific instruments necessary to conduct experiments—precise scales, barometers, microscopes, chemicals, and any number of devices—a virtuoso relied upon artisans of various trades. For information about particular phenomena and locations to which he did not have access, such as volcanoes or the ocean floor, a natural philosopher was forced to rely upon the testimony of witnesses to these and other occurrences through travel accounts or personal interviews. Also, a host of records about experimental outcomes circulated throughout literate society as bits of useful knowledge for understanding the workings of nature. Reports both extraordinary and mundane, but relevant to the natural world, constantly bombarded a well-connected virtuoso in his private relations. In other words, for the daily pursuit of natural experimental philosophy in seventeenth-century England, knowledge, or the means to seek it for oneself, arrived from all directions. Reality

[22] *The Correspondence of Henry Oldenburg*, eds. A. R. and M. B. Hall, 13 vols. (University of Wisconsin Press; Mansell; Taylor and Francis, 1965–1986). Oldenburg painstakingly collected and disseminated correspondence at home and abroad, and communicated many scientific projects and discoveries in the Society's *Philosophical Transactions*.

necessitated that special mental equipment be mobilized for dealing with diverse situations and various sources of knowledge.

This study will demonstrate that consideration and assessment of skill and experience served as important mental tools that English natural philosophers used to cope with the many rival theories and the many relevant actors involved in the production of knowledge during the latter half of the seventeenth century. As stated, the primary subject of my study is Robert Boyle, who stood as the quintessential figure for pre-Newtonian English experimental philosophy. As the leading example of the kind of natural philosopher presented by the Royal Society, Boyle was renowned in intellectual circles and revered by many prominent thinkers of his day. In writing about his experiments and other natural-historical topics, Boyle provided much of the factual matter with which other experimentalists operated—properties of air, color, cold, specific gravity, and chemical combinations.[23] Being born the youngest son of the Earl of Cork—though never taking a peerage himself—further enhanced his standing as the exemplar of the new science in seventeenth-century England. More importantly, Boyle was perhaps the most active English defender of both the experimental program and the mechanical view of nature essential to the new science, and he consistently asserted these ideas against rival theories, including Aristotelian scholasticism. Among his contemporaries, Boyle most thoroughly explained and defended the importance of the new experimental natural philosophy and its methods through his prolific religious and scientific tracts.[24]

[23] Steven Shapin claims further that "Boyle arguably entered more matters of fact in the register of the seventeenth-century English experimental community than any other individual"; see *Social History of Truth,* 126.

[24] For a particularly fawning account of Boyle's importance to experimental science from one of his

Thus, for an examination of the ways in which considerations of skill and experience served the active experimental philosopher in England, Boyle proves invaluable. Although he had a reputation for being detached and he often sought long periods of solitude, especially during times of ill health later in life, his connections, as well as records of his dealings, were vast. On a typical day, Boyle could establish meaningful contact with a dozen or more persons relevant to his philosophical practices. Many foreign and domestic guests frequented his Oxford and London homes. As a matter of course, he often spent hours reading from travel accounts, literature, and all manner of writing related to chemistry, alchemy, botany, trades, experiment, religion, and philosophy; and he frequently shared his opinions about these relevant bits of information throughout his writings. For work in his private laboratory, Boyle often employed several assistants at a time to perform any number of anonymous tasks, or the crux of the actual experiments themselves. Outside his London dwellings, his experimental practices also necessitated contact with various merchants or artisans for the fine instruments and mechanical components his experiments required—most notably his famous air-pump trials for which he collaborated with Robert Hooke (1635–1703). Furthermore, in the Royal Society's London meeting rooms at Arundel House or Gresham College, Boyle and dozens of other Fellows gathered to witness the experiments proposed by its members and often performed by Hooke as the Society's Curator of Experiments.

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contemporaries, see Joseph Glanvil, *Plus Ultra, or the Progress and Advancement of Knowledge Since the Days of Aristotle* (1668), facsimile reproduction with an introduction by Jackson I. Cope (Gainsville, Fla.: Scholars' Facsimiles and Reprints, 1958), 92–110. Among Boyle's works, Glanvill wrote, one could find "the most generous knowledge and the sweetest Modesty, the noblest discoveries and the sincerest Relations, the greatest Self-denial and the greatest Love of Men" (93).

During the previous two decades, Barbara Shapiro and Steven Shapin have approached separately the importance of credibility and testimony to the establishment of matters of fact in seventeenth-century science, using Boyle as a key example.[25] In the first chapter I explore the ways that the concepts of skill and experience prove useful and provide important corollaries to Shapiro's sometimes overly-legal and Shapin's predominately social perspectives. In the next chapter I elaborate how Boyle demonstrated a preoccupation in his writing for the impact of skilled artisans, or lack thereof, on experimental practice. Rose-Mary Sargent asserts that the English experimental program was built more upon the contingencies of experimental practice itself than anything resembling social causation, such as the transplantation of other gentlemanly practices.[26] Consistent with this vein, we find instances where Boyle declared some alteration, success, or abandonment of particular experiments due to matters relating to the skill and availability of artisans, who supplied his experiments with important instrumentation and mechanisms. Additionally, Boyle defended tradesmen's skills and ingenuity in their special fields as proper components of natural philosophy and knowledge production. As part of this chapter addressing experimental contingencies, I also demonstrate how Boyle's awareness of and concerns for his readers' wide-ranging levels of experimental skill and their potential attitudes toward manual work help us further understand the popularization of science in the seventeenth century. Boyle reveals a subtle awareness of the gentleman's attitude toward the manual labor involved in conducting experiments. Thus, he consistently advertised those experiments that required

[25] Shapiro, *Probability and Certainty,* chapter 2; Shapin and Schaffer, *Leviathan and the Air-Pump,* chapter 2, especially 55–60; Shapin, *Social History of Truth*.

less expertise and skill in a subtle campaign of propaganda for the popularization of experimental activities. In the third chapter I examine the requisite skills of the prudent experimental natural philosopher, in contrast to the practices of scholastics, particular kinds of chemists, and even artisans themselves. It is evident that contentions with other philosophical systems often were not entirely theoretical, but rather practical, involving skillful perception and communication. In conclusion, I situate this study within the scholarship and examine some of Boyle's forward-looking statements about the improved skills of future generations and their impact upon the advancement of natural philosophy and the improvement of humankind.

Before continuing, some etymology will prove useful for establishing seventeenth-century denotations and connotations of the terms *skill* and *experience*. In the process, I hope to demonstrate their importance as components of *knowledge* and also delineate their relationship with other relevant terms suggesting knowledgeability, such as general *education* and *learning*. As the discussion of the seventeenth-century backdrop above should suggest, the production of knowledge was of great importance to the various philosophical systems, yet the proper means of its production, as well as what qualified for knowledge were by no means self-evident. Accurately understanding the value of these terms and how they applied to topics in Boyle's writings—credibility, experimental contingencies, and philosophical skills—requires knowing the full range of their meanings.

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[26] Sargent, "Learning from Experience."

In seeking to show that the identifiable philosopher subsumed the work of the anonymous skilled technician, Steven Shapin establishes what is for him a useful notion of *skill*: "a species of manipulative work and its associative capacities which was *defined by relevant actors* in practical opposition to notions like knowledgeability."[27] Therefore, while skill might have been treated as an elevated form of labor, it also sat at one end of an "evaluative opposition at the other pole of which was some notion of *knowledge*, conceived not as work but as thought."[28] This polar relationship is what Shapin refers to as a "knowledge-skill distinction." Further, Shapin identifies *experience* through contrast: "The rational knowledgeability which historians recognize Boyle possessed, which he attributed to himself, and which contrasted to his assistants' mere experience, was both justification of his authority over the scene [the laboratory] and an attribution of value."[29] Thus, according to Shapin, at least in particular experimental scenes, *knowledge* expressed a capacity to define and direct the experimental action being done and was far superior to mere *skill* and *experience*.

Some distinction necessarily existed in ordinary seventeenth-century usage, as today, when people employed such terms as *skill* or *knowledge* or *experience* or *learning*. And it seems clear that when Boyle used *skill* or *experience* he did intend a distinction between these notions and those of *knowledge* and *education*, often expressed through the adjective *learned*.[30] But I believe that Shapin errs on two related counts. One, he attaches

[27] Shapin, *Social History of Truth*, 361. Italics are his.
[28] Ibid., 361.
[29] Ibid., 382.
[30] For example, he wrote, "The observations that tradesmen can supply us with, though they are not probably at any one time so accurately made by them, as they would be by a learned man." *Usefulness, II, sect. 2, Works,* 3:444.

each category of terms too solidly to their respective social castes; secondly, he assumes an overly denigrated place for *experience* and *skill* in seventeenth-century usage. Beyond their meanings as words, Shapin casts the words themselves into firm social categories and uses them to serve as the only applicable terms for their human counterparts. That is, *skill* and *experience*, it would seem, were the exclusive descriptors for the most laudable traits of Boyle's assistants or artisans, while *knowledge* stood to represent the gentlemen. Significantly, however, Boyle and his contemporaries often allowed these terms to cross social boundaries and to exist as subcategories of one another in varying combinations. Particularly, we find the attributes of skill and experience relevant to the educated gentlemen. For instance, Boyle explained his fitness to write upon a subject through his own experience with nature and his familiarity with the skills of the tradesmen, in combination with his knowledge: "Those, that are mere scholars, though never so learned and critical, are not want to be acquainted enough with nature and trades," and thus cannot match Boyle's own skillful knowledgeability.[31] Sometimes Boyle's usage demonstrates how experience could be conflated with gentlemanly knowledgeability: "I know an ancient and landed gentleman, who communicated to me upon his own knowledge and experienced way of making wheat grow and prosper well in mere clay."[32] In addition, skill sometimes applied to the mental work of the philosopher. The naturalist John Ray (1627–1705) referred to the possibility of describing all the visible works of God as a "task far transcending my Skill and Abilities; nay the joynt Skill and Endeavors of all men now living, or that shall live after a Thousand Ages...For no man can find out

[31] *Usefulness, II*, *sect. 2, Works,* 3:395.
[32] Ibid., 406.

the Work that God maketh from the beginning to the end."[33] Here Ray seems to have used "skill" and "ability" to show both the limits of applied activity and the limits of knowledge and understanding. This example pairs well with Boyle's reference to natural philosophers as men "thoroughly skilled in [nature's] laws, and acquainted with a vast number of her productions."[34] Further, Boyle wrote that knowledge about the physical properties of nature could enable one to perform things "whereto even mathematical instruments, and skill in mathematicks are thought requisite."[35] Skill was certainly an attribute that applied to the educated gentlemen and his specific knowledge.

The way Boyle used language in the second part of his *Usefulness of Experimental Natural Philosophy* demonstrates the ways he perceived a close connection between physical labor and knowledge.[36] Thus, Boyle used a juxtaposition such as this in one of his essay titles: "Of Doing by Physical Knowledge What is Wont to Require Manual Skill" (457–469). Further, in justifying what he saw as a necessary communication between philosophy and trades, Boyle referred to them both as "parts of learning hitherto strangers with their respective skills" (401). Discussing the usefulness of natural philosophy for gaining power over nature, Boyle mentioned the benefits that "skill in physiology is able to supply mankind with" (423). Elsewhere, referring to the natural philosopher—not the tradesman—Boyle described that the natural philosopher could assist communication between different trades "as far as his skill reaches" (450).

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[33] John Ray, *The Wisdom of God Manifested in the Works of the Creation* (1691) Anglistica and Americana 122 (New York: Georg Olms, 1974), Preface.
[34] *Usefulness, II, sect. 2, Works,* 3:403.
[35] Ibid., 459.
[36] *Usefulness, II, sect. 2, Works,* 3:392–495. Page references in the text apply to this work until otherwise noted.

Boyle often thought of knowledgeability in the most practical of terms. He wrote thoroughly about the practical uses of knowledge and the knowledge to be gained from insights into areas where skill applied, such as in the trades (446). Likewise, "philosophy" could supply great help to "the office of manual dexterity" as "a knowing head may do what is thought not performable but by a skillful hand" (457).

Also useful for eliminating suggestions of firm social categorization of terms are instances in which Boyle applied the descriptor *ingenious* as a transcendent adjective for both the gentlemen and the commoner, and for the mental activity of reasoning as well as work that was clearly more practical and experiential. Writing about the ways to make barren land productive, Boyle related the methods of "some ingenious husbandmen" with effective techniques (410).[37] On the same page, he shared an example of a particularly "ingenious gentleman" with fruitful crops who confided to him yet "another specimen of his skill" (410). Even outside the topic of experimental natural philosophy, Boyle demonstrated the importance of the mind's ingenuity. Addressing the "reconcileableness" of reason and religion, Boyle wrote in his preface that he "would have reason practice ingenuity as well as curiosity, and both industriously pry into things within her sphere" and acknowledge those things beyond it.[38] Clearly, Boyle mobilized a rhetoric of skill in order to put a practical (and positive) connotation on what otherwise was a purely metaphysical use of the mind.

Although it is my purpose to eliminate any precise social categorization of the concepts *skill* and *experience* and to suggest a greater esteem among seventeenth-century

[37] Also, Boyle wrote of "a very ingenious artificer, who had contrived an instrument useful to others." Ibid., 418.

virtuosi for these traits, I do not wish to blend their separate meanings with that of *knowledge*. Boyle and his contemporaries often used these terms in ways that implicitly set them apart from general knowledgeability. Boyle and others applied the epithet *learned* copiously and seldom with specific explanation—perhaps relying on an unspoken seventeenth-century assumption about what it signified. Normally *learned* seems to have implied knowledgeability in a generally educated and worldly sense: "eminent physicians and other learned men," "a learned divine," "a learned and applauded writer," or "the learned Jesuit Zucchius," for example. Although occasionally it might apply to a particular area: "intelligent persons in matters of this kind."[39] *Skill* and *experience*, on the other hand, were regularly used in connection with the application of work toward and specialized knowledge in particular fields, practices, and studies, such as metallurgy, physiology, glass-blowing, or mathematics: "the experienced chirurgeon Fabricius Hildenus's treatise"; "The arts of tillage, cattlekeeping, dairies, wood, flax and hemp, hops, orchards, beer, and cider" all "require some skill and are capable of much improvement."[40] They could apply to pursuits fitting for both genteel and nongenteel persons, both mental and manual labor, and both philosophers and artisans alike.

The *Oxford English Dictionary* is, of course, of some use here. The term *skill* (and its various spellings and forms) had connotations for reference to mental acumen, particularly in Middle English: "1. a. Reason as a faculty of the mind; the power of discrimination." By the seventeenth century, the term came to reflect application in specialized, practical matters, while maintaining significant mental aspects: "5. a. . . . to

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[38] *Reason and Religion, Works,* 4:155.
[39] *Spring, Works,* 1:1.

have discrimination or knowledge, esp. in a specified matter."; "6. a. . . . Capability of accomplishing something with precision and certainty; practical knowledge in combination with ability; cleverness, expertness. Also, an ability to perform a function, acquired or learnt with practice."; and "7. Knowledge or understanding of something."[41] *Experience* tended to refer to direct knowledge in particular matters, but with interesting origins that shared roots with the word *experiment*: "1. a. The action of putting to the test; *to make experience of*: to make trial of.; Proof by actual trial; practical demonstration."; "3. The actual observation of facts or events, considered as a source of knowledge." Finally, *experience* applied to knowledge of particular subjects: "8. The state of having been occupied in any department of study or practice, in affairs generally, or in the intercourse of life; . . . the aptitude, skill, judgment, etc. thereby acquired."[42]

Even though skill and experience applied to both the practical abilities of the mind and attainment of knowledge through practice, these terms were usually absent of knowledge gained through general, formal education and instruction. Of course, the term *knowledge*, too, could have experiential connotations: "5. a. The fact of knowing a thing, state, etc., or (in general sense) a person; acquaintance; familiarity gained by experience."; "10. Acquaintance with a branch of learning, a language, or the like; theoretical or practical understanding of an art, science, industry, etc,: skill *in* or *to do* something." Yet often it meant information or understanding not practically come by: "8. c. *Philosophical knowledge about*, *knowledge by description*: knowledge of a person, thing, or perception gained through information or facts about it rather than by direct

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[40] *Usefulness, II, sect. 2, Works,* 3:408.
[41] *Oxford English Dictionary,* 2nd ed., s. v., "skill."

experience."; "11. In general sense: The fact or condition of being instructed, or of having information acquired by study or research; . . . learning; erudition."[43] Thus, the terms could have significant overlap in their applied meanings, yet use of *knowledge* carried with it the implication of education, study, and instruction, whereas *skill* and *experience* usually implied directly applied or directly gained, respectively.

Understanding the connotations and potential denotations of our key terms proves significant to each chapter of this study. In chapter one I demonstrate that when Boyle referred to the skill or experience of a relater of facts, the terms seldom implied specific social categorization, but merely direct, repeated, and specific knowledge of particular subjects. Elaboration of these concepts in chapter two will elaborate the contingencies associated with skillful (or unskillful) knowledge about and application of particular kinds of work and the subsequent impact upon broader philosophical knowledge about the world. Again, here, skill applied to both the mental work of a philosopher and the physical work of the tradesmen. For the popularization of experiment among Boyle's gentlemanly readership, new and unfamiliar skills needed to be elaborated. That experimental philosophy involved such mental and physical work necessitated not just recommending a skillful approach to ensure experimental success but also allaying apprehension about experimental mishaps and curbing attitudes toward manual skill. In the third chapter, we see that Boyle's writings further reveal that he conceived of natural philosophy as work. Therefore, I will flesh out Boyle's perceptions of proper philosophical skills, and see how they applied to the study of nature in a manner that was

[42] *Oxford English Dictionary,* 2nd ed., s. v., "experience."
[43] *Oxford English Dictionary,* 2nd ed., s. v., "knowledge."

consistent with Boyle's portrayal of God as a skilled artisan-creator. In conclusion, I address how Boyle perceived that the skills of an advancing scientific age would deliver improvement to natural philosophy and all humanity.

CHAPTER 1

SKILL, EXPERIENCE, AND CREDIBILITY

Robert Boyle and his contemporaries bolstered the probability of matters of fact derived from their own experiments and observations—and often the hypotheses which they supported—with testimony from those who possessed some expert, skillful, or experiential knowledge about relevant phenomena. The credibility components most pertinent in these cases had little to do with the virtue of status. Rather, these experts—for example, jewelers, miners, and physicians—established their credit through pertinent skills or experiences in specific matters.

Avenues to Credibility

As a matter of course, the testimony of eyewitnesses regularly vouched for the experimental outcomes of the Royal Society at Gresham College and Arundel House. Yet the experiments performed beyond the confines of the Society's official meeting places also needed the enhanced plausibility that witnesses provided. Heliodorus, a character in Boyle's *Dialogue on the Transmutation and Melioration of Metals*, interjects his approval for Pyrophilus' "discretion in taking an Assistant and a Witness, because in nice and uncommon Experiments we can scarce use too much circumspection, especially when we have not the means of reiterating the tryal." To this Pyrophilus agrees that such "cautiousness is a very requisite qualification for him that would satisfactorily make

curious experiments."[1] But just how was one to credit the testimony of witnesses? At least for the witnessing of particular experiments the answer rested, in part, with multiplicity. As in legal matters, the authority of testimony, and thus consent to the matters of fact that it compelled, benefited from concurring statements. Boyle often referred to the number and qualification of the eyewitnesses to his experiments.[2] Robert Hooke's practice of having witnesses to particular experiments sign a register for the proceedings at the Royal Society further demonstrates the importance of eye-witnesses to the business of the Society's activities.[3] Yet, as I described in the introduction, the virtuosi gathered information about the natural world from sources beyond the experiments of Fellows. Thus, Boyle and others wrestled with assessing the credibility of relations from travel accounts, tradesmen, and personal acquaintances.

Modern scholars direct attention to the importance of witnessing for English experimental science and the Royal Society.[4] When one considers the growing acceptance of probable knowledge during the seventeenth century, the relevance of credibility, and thus skill and experience, seems apparent.[5] Credibility is integral to Barbara Shapiro's examination of evolving conceptions about the nature of truth in various fields—law, religion, science, history, and literature—during the seventeenth century.[6] The seventeenth century, she claims, witnessed a breakdown in the long

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[1] Boyle, *Dialogue on the Transmutation and Melioration of Metals*, in Principe, *Aspiring Adept*, 282.
[2] Shapiro, Probability and Certainty, 179, 187.
[3] Shapin and Schaffer, *Leviathan and the Air-Pump*, 56, 58.
[4] See note 6 of Introduction.
[5] The purpose of the following analysis is not to expound seventeenth-century philosophical traditions, per se, but to suggest an emerging probabilistic way of conceiving knowledge for which testimony, and therefore skill and experience, were relevant.
[6] Shapiro, *Probability and Certainty*; Shapiro, *Beyond "Reasonable Doubt."*

philosophical tradition that kept science, knowledge, and certainty, on the one hand, divided from opinion, probability, and rhetoric, on the other. So that by the end of the seventeenth century "most English thinkers, no matter what their field of inquiry, had ceased to believe that their labors would produce the certitude or 'science' that had for centuries been the goal of the philosopher."[7] Instead, they gradually settled for perceiving truth, certainty, and matters of fact as a continuum, at the apex of which stood "moral certainty," a term borrowed from theology that described the certainty of knowledge built on human experience and testimony of those experiences.[8] Thus, along with opinion, conjecture, experience, and probability, credibility became a relevant category for the natural philosopher of the seventeenth century.

Although Rene Descartes (1596–1650) and Francis Bacon labored to establish philosophy and truth on more certain bases, doubts about the need for sharp distinctions between scientific certainty and probabilistic opinion nonetheless arose. We know, of course, that British science developed an empirical program influenced by Baconian method and its inductive certitude. Yet probabilistic conceptions were evident throughout the seventeenth century, and refinements in knowledge-making resulted in new distinctions between logical/mathematical demonstration and moral certitude, which gained in stature.[9] Whereas Boyle and others preferred first-hand experience, they

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[7] Shapiro, *Probability and Certainty*, 4. Also see Shapin and Schaffer, *Leviathan and the Air-Pump,* 23–24.
[8] Shapiro, *Probability and Certainty,* introduction; Shapiro, *Beyond "Reasonable Doubt,"* 8. Rose-Mary Sargent places even greater emphasis of certainty on this category of moral demonstration. Because Boyle did not consider the physical realm to be susceptible to mathematical demonstration and experimental philosophy followed the way of experience, moral demonstration was his preferred mode of proof. See Rose-Mary Sargent, "Scientific Experiment and Legal Expertise: The Way of Experience in Seventeenth-Century England," *Studies in the History and Philosophy of Science* 20, no. 1 (1989), 28–39.
[9] Shapiro, *Probability and Certainty,* 15–17.

accepted the need to rely from time to time upon the reports of others, especially for phenomena otherwise unapproachable. While investigating the properties of cold, Boyle needed witnesses to extremely cold temperatures that England's temperate climate could not provide. He addressed the situation most succinctly: "I must either make use of other men's testimonies, or leave some of the remarkablest phenomena of cold unmentioned."[10]

Therefore, in dealing with testimony, which was an unavoidable necessity, the scientific community adopted and refined existing traditions for evaluating the credibility of witnesses. Shapiro elaborates many of the considerations involved in assessing the credibility of testimony.[11] Besides the number of witnesses, the reader or listener had to take into account each witness's reputation for honesty, skill, and knowledge. They also considered how testimony might reflect the bias of cultural or educational background. Potentially, this was highly significant, as the scientific community was dealing sometimes with accounts of different phenomena from all around the world. In short, probability could effectively pass for an acceptable level of knowledge, but probability often rested on testimony, which had to be assessed through an evaluation of these and other credibility components. For Shapiro, this probabilistic conception of knowledge culminated in the work of John Locke (1632–1704), whose maxims for credibility assessment summarize the seventeenth-century approach.[12] In Book IV of *An Essay Concerning Human Understanding,* Locke asserted that the two "grounds of probability"

[10] *Cold, Works,* 2:476.
[11] Shapiro, *Probability and Certainty,* 21.
[12] Ibid., 70. Shapiro writes, "In the course of the seventeenth century, English philosophy of science moved from a Baconian to a Lockean search for truth."

were one's own experience and the testimony of others.[13] Further, he recommended in his explanation six maxims for the evaluation of testimony, including the skill of a witness.[14]

Locke's statements are also essential to Stephen Shapin's analysis of seventeenth-century credibility in *A Social History of Truth*, in which he, too, elaborates the importance of credibility issues for the creation of scientific matters of fact. His handling of "the practical management of factual testimony" adeptly demonstrates the interaction of credibility components and comprises the most balanced and complete chapter of the work.[15] Here, Shapin shows the relationship and overlap of Locke's several maxims for the evaluation of testimony—including knowledgeable and skilled sources—in Boyle's work.[16] In the main, however, Shapin is concerned with gentlemanly codes and the role of identity in the construction of knowledge. Shapin examines the prescriptive "courtesy literature" in order to find the features of gentlemanly culture that defined the English gentleman. Continuing social themes evident in his work with Simon Schaffer, he asserts that the way in which certain types of scientific knowledge were made and their credibility secured is a "story about the relationship between science and gentlemanly conduct" in early modern England.[17] The argument follows that English experimental philosophy emerged as a new culture when virtuosi of the day purposefully relocated conventions, codes, and values of gentlemanly conduct into the practice of natural

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[13] John Locke, *An Essay Concerning Human Understanding,* edited by Alexander Campbell Fraser, vol. 2 (New York: Dover Publications, 1959), 363–368.
[14] Ibid., 366. The six maxims that he listed were 1) number of witnesses, 2) integrity of a witness, 3) skills of the witness, 4) design of the author, 5) consistency of the parts and the circumstances of the relation, and 6) contrary testimonies.
[15] Shapin, *Social History,* chapter 5, especially 211–230.
[16] Ibid., 218–221.
[17] Ibid., xvii.

philosophy. These gentlemanly practices proved useful to the natural philosopher in seventeenth-century England as means to provide "working solutions to problems of credibility and trust which presented themselves at the core of the new empirical science."[18] The features of the culture that defined the gentlemen and apply best to issues of credible testimony in Shapin's work are "free action" and "virtue," the general indicators of reliable truth-telling. The gentleman's free movement in society as an independent agent, oblivious to party or interest, founded the guarantees of the truth of what the gentlemen avowed.

For the exemplar of his assertion that truthfulness was situated in the traditional culture of honor, Shapin presents Robert Boyle, "perhaps the greatest master of scientific credibility."[19] Boyle (and others) attempted to construct a new and usable identity of the experimental philosopher out of the cultural materials of gentlemanly society. Similar to Shapiro, Shapin follows a moral history of scientific knowledge claims. But rather than place these developments in a larger intellectual exchange and evolution of seventeenth-century England, he emphasizes a direct correlation between matters of scientific knowledge and knowledge about the gentlemanly credentials of the relater. In short, gentlemanly identity was the prime resource in making credible knowledge.[20]

Lawrence Principe has recently taken issue with Shapin. In particular, he attacks the assertion that the fellows of the Royal Society constructed scientific discourse according to a model of civil conversation in order to ensure gentlemanly decorum during

[18] Ibid., xxi.
[19] Ibid., xxviii.

disputes. Instead, in examining Boyle's "lost" *Dialogue on Transmutation*, Principe finds that "disputants speak sharply to one another, ill temper is displayed, the Society splinters into competing sects, and claims are firmly negated."[21] Additionally, he discovers that authors of older accounts of the alchemical transmutations of metals also used testimony and literary technology to multiply witnesses, and that they, too, demonstrated the importance of high-born witnesses. Thus, he claims, the practice was not unique to Robert Boyle or the Royal Society.[22] Most importantly, he hints at a theme that is the central business of this chapter. In Boyle's *Dialogue*, the character Erastus' comments demonstrate that the differences among witnesses do not involve their social status so much as they point to awareness of their *skill*.[23] I do not wish to present Principe's points nor the conclusions of this study as counter-theses to Shapin's arguments concerning connections between gentlemanly culture and English science. Clearly the evidence from Boyle alone highly suggests these significant points, which are clearly necessary for a truly complete understanding of seventeenth-century science. But with this complete picture as an ultimate goal, I think it crucial to cast more attention toward the practical concepts of skill and experience as significant components of Boyle's credibility assessment.

Shapiro, while brilliant in placing probability in an interdisciplinary seventeenth-century context, is often overly-legal in describing testimony and credibility in relation to

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[20] In a related vein, he extends ideas developed in *Leviathan and the Air-Pump,* namely, that the maxim of honorable conduct was transferred to the laboratory and philosophic practice in general, providing means to dissent without scientific disaster. Shapin and Schaffer, *Leviathan and the Air-Pump*, 72–73.
[21] Principe, *Aspiring Adept*, 71–72, also 24–25.
[22] Ibid., 109–110
[23] Ibid., 109

natural philosophy in seventeenth-century England. Issues of the number of witnesses, the believability of witnesses, unsworn testimony, conflicting testimonies, and so on, clearly were pertinent to the knowledge gained from eyewitness testimony in natural philosophy, and I do not wish here to downplay their significance to the production of knowledge. Multiplicity of witnesses, for example, is one obvious theme throughout Boyle's writing. In many instances he displayed the compounding of witnesses to experiments at the Society or of observed natural phenomena. For example, multiplicity of witnesses, as well as many other credibility components, are evident in sections of *The General History of Air* (1692): "A learned man, that lived at Jamaica, assured me. . . . Mr. Nickson, who was four year governor of the English colony in Hudson's bay, answered me. . . . A learned traveller, that made some considerable stay among the high Pyrenean mountains, answered me. . . . The Russian emperor's physician confirmed to me. . . . A very inquisitive person that visited the Pyrenean mountains, answered me. [and] A heedful person, that frequented the coast of Sumatra in the South-Sea, answered me."[24] Obviously, Boyle intentionally multiplied his witnesses and pointed to a wide range of credibility traits.[25]

Boyle and late seventeenth-century virtuosi, however, faced many other important considerations because they often assessed testimony concerning matters for which the experience and skill of the relater proved the most relevant—a phenomenon given little

[24] *History of Air, Works,* vol. 5:692–694.
[25] This transference of legal language was also highly evident in the writings of Joseph Glanvill (1636–1680), particularly those pertaining to witchcraft. Glanvill established disinterestedness, preferred direct eyewitnesses, and wrote of the "truth of the Matter of Fact, by sufficient Witnesses." See Joseph Glanvill, *Saducismus Triumphatus: or, Full and Plain Evidence Concerning Witches and Apparitions* (Gainesville,

direct and elaborate attention by modern scholars. In other words, Boyle and others paid attention to not just a witness's knowledge of an independent event itself, but also his experiential knowledge of and skill with similar phenomena, of which the particular event is but one example. The various trades that supplied society with all manner of products derived from natural resources had existed for countless centuries. Boyle and other seventeenth-century virtuosi who attempted to explicate nature's workings thought it only sensible that they consult its existing experts. While Shapiro also discusses John Locke's overt statements dealing with considerations of a witness's skillful knowledge in the process of weighing testimonial claims, she does not provide adequate examples from Boyle's work, preferring instead to emphasize themes such as closeness to an event or honest relation. Yet, Boyle often cited testimonials from witnesses whose expertise or skill in a specific area were the subjects of assessment. These concepts are necessary to fully demonstrate the complete subtleties evident in the assessment of knowledge claims during the seventeenth century.

Although he does not ignore other credibility criteria, Shapin overstretches the notion of gentlemanly virtue to assert that it was the gentleman who possessed the monopoly of virtuous reputation in seventeenth-century England, and that a gentlemanly reputation, when mobilized, could almost exclusively bolster "matters of fact" derived from experiments, natural phenomena, or other observations. Elsewhere, Shapin has written that, while Boyle and his colleagues wanted to celebrate the ingenuity of the craftsmen and put on the "guise of the humble artisan" themselves, this should not imply

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Fla.: Scholars Facsimiles and Reprints, 1966). Shapiro discusses testimony and witchcraft in *Probability*

that they "treated artisans as on par with philosophers, or that they regarded the testimony of artisans on par with the gentleman."[26] Whereas this argument clearly possesses plausibility as a description of social relations in early modern England, we will see that when Boyle used testimonials for which he emphasized the witness's skill and experience, regardless of social bearing, assertions about the primacy of gentlemanly virtues are rendered incomplete. It is not my purpose here to assert that either the Society's fellows or Restoration society considered the testimony of the artisan to be "on par" with that of the gentleman *in general*. But clearly, where the characteristics of skill and experience applied more pertinently to matters of fact concerning the natural world, they often silenced gentlemanly credentials. Shapin hints at this himself as he quotes Boyle: "That even of honest and sincere Witnesses, the Testimony may be insufficient if the matter of fact require Skill in the Relator."[27]

Thus, whereas Shapiro and Shapin provide essential and revealing analyses of seventeenth-century credibility assessment, for the subtopic of practical skill and experience, they stand as useful starting points. I wish to provide necessary elaboration and balance by demonstrating the importance of the rhetoric of skill and experience in

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and Certainty, chapter 6.

[26] Shapin and Schaffer, *Leviathan and the Air-Pump,* 130–131.

[27] Shapin, *Social History of Truth,* 230. Shapin cites *Boyle Papers,* vol. 9, f. 25v.

I might add that Boyle himself perceived virtue as a concept that transcended social station. He criticized the high-born who ascended to power only to win public acclaim, or those who sought the rewards of virtue without having ever earned them. (J. R. Jacob, *Robert Boyle and the English Revolution*, 54–55) Also, in many ways he rejected his aristocratic status and denounced the lazy trappings of family wealth, such as "aristocratic sloth" and time-wasting. (Ibid., 72) Furthermore, Boyle expressed concern about the dubious faithfulness and honesty of members of the gentlemanly caste. For example, in "An Essay About the Loss on Many of His Writings" (1688), Boyle cited plagiary of his writings and fraud of those who stole credit for his experiments. (*Works,* 1:lxxvi) Certainly these plagiarists had come from the educated intellectual class. In examining Boyle's "Aretology," J. R. Jacob asserts that Boyle believed knowledge—from both experiment and formal learning—could be productive of virtue. (Jacob, *Robert Boyle,* 76)

Boyle's writing in matters of credibility. These concepts comprise an illuminating supplement both to status indicators such as formal education and gentlemanly virtue and to legal terminology such as multiplicity or closeness to an event. In fact, one inescapable conclusion that will arise is that Boyle often built credibility any way he could—as a rhetorical expedient. If an overall theoretical point could be bolstered from the relation of a virtuoso who witnessed some relevant experiment, then Boyle could emphasize the reputation for honesty or learning of the relater. If, on the other hand, he were seeking to, say, strengthen the plausibility of an experimental outcome with testimony from an artisan or tradesman, then Boyle could bolster his argument by emphasizing the skill and experience of the craftsmen. While evidence of these conveniences is sometimes inescapable, one cannot find the motive of rhetorical expediency in other significant areas of Boyle's programmatic writing. To make this point clearer I will conclude this chapter with Boyle's statements from *Some Considerations Touching the Usefulness of Experimental Natural Philosophy* (1663) and other tracts, in which he overtly shared what he perceived as the value in the philosopher directly consulting tradesmen. Their skill and experience in particular areas assisted the virtuosi in explicating undiscovered phenomena of nature. Thus, the conclusion to be drawn is that Boyle considered the personal traits of skill and experience to be significant components of knowledge making.

Skill and Experience: Gems of Credibility

Boyle did not confine his understanding of experience to the strictest personal sense. Besides conceiving of experience as that which people attained through their own senses, he recognized that which vicariously "accrues to us by the communicated

testimony of others."[28] Experience was, of course, the centerpiece of the experimental way of knowledge production. In the common seventeenth-century philosophical rhetoric, the rational suppositions used for centuries by Aristotle's followers succumbed to the new hands-on exploration of nature propagated by the Royal Society. That Aristotle and his medieval interpreters really advocated and pursued some level of observation and experiment usually mattered little to Boyle and other virtuosi. For many seventeenth-century natural philosophers, the old served as a convenient foil, necessary for stressing the laudable new way of experience and experiment, whether directly gathered or obtained through the relations of others.

The implication of "ratiocination" rather than experimental evidence, when mobilized, could explode arguments presented by the experimental program's critics.[29] Boyle's well-recorded exchanges with Thomas Hobbes (1588–1679) illustrate the importance of experience in the seventeenth century. In addition to arguing the metaphysical significance of the air's properties under experimental conditions, they also disputed the nature of cold.[30] For one, Boyle decried that Hobbes "scruples not to take to his readers of his demonstrations." Rather, Boyle charged, Hobbes' assertions about the quality of cold attempted their strength from unclear reasoning and fancy writing, which "has had no small effect upon the many, who not knowing, how indulgent some writers are wont to be of the issues of their own brain, as such, are apt to mistake confidence for evidence."[31] Boyle contrasted his own way to that of Hobbes' with the cannon-fire of the

[28] *Christian Virtuoso, I, Works,* 5:525.
[29] *Examen, Works,* 1:187, 206.
[30] Boyle, "An Examen of Mr. Hobbe's Doctrine Touching Cold," *Cold, Works,* 2:687–737.
[31] Ibid., 687.

experiential way of knowledge production: "We find by experience, that cold is always more remiss in places, where it rains, and where the weather is cloudy. . . . We also find by experience, that in deep wells the water freezes not so much, as it doth upon the superficies of the earth. . . . We find moreover by experience, that ice is lighter than water."[32]

The testimony of experience could overturn "vulgar" notions about the components and functionings of the natural world, and Boyle used it copiously throughout his tracts. For instance, Boyle remembered his "many opinions about the submarine parts, that I among many other men, thought probable, I found cause to change" after conversing with a famous diver who stayed several hours at the bottom of the sea with the help of a breathing apparatus.[33] Even an ordinary seaman or traveler who sailed with Columbus along several coasts, and passed up and down through the country "was able at his return to inform men of an hundred things, that they should never had learned by Aristotle's philosophy, or Ptolemy's geography," and that might "rectify divers erroneous assumptions and mistakes."[34] In accord with one of Boyle's propositions in *The Christian Virtuoso, Part I* (1690)—that "we ought to believe divers things upon experience . . . which, without that information, we should judge unfit to be believed"—he recommended changing opinions of persons that were based merely upon reputation when the "testimony of experience" contradicted prior notions of a person.[35]

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[32] Ibid., 689. Boyle's criticisms of Hobbes in the matter of the air-pump experiments is similar, as he denounced Hobbes' lack of experimental skill. See *Examen, Works,* 1:186.
[33] *Christian Virtuoso, I, Works,* 5:531.
[34] Ibid., 530.
[35] Ibid., 526, 527.

Experience and skill were qualities that lent obvious credibility to relations from tradesmen and artisans when Boyle was seeking particular matters of fact. They were personal traits that Boyle imputed to those who had specific and repeated experience or who possessed skillful knowledge of natural resources, and he did not feel compelled in many instances to bolster their potency with suggestions of education, social status, or veracity. In a letter to Henry Oldenburg in September 1673, Boyle recommended an account about ambergris because it "was not written by a Philosopher to broach a Paradox, or to serve a Hypothesis," but because it was written by a "Merchant or Factor for his Superiors."[36] Boyle further shared his wish that "more notice than usual were taken and given of the Natural Rarities that occur to Merchants and Sea-men."[37] In another example, Boyle, describing what immense force one found in the freezing of water, first pointed to those easily observed effects occurring in winter. But for "more considerable" and "less obvious" instances, Boyle shared the testimony of an "ingenious stone-cutter."[38] For yet another production of nature, Boyle consulted a "very skillful cutter and polisher of diamond" with nearly twenty years experience in order to demonstrate the hardness of diamonds.[39]

Beyond merely relying upon the skill and experience of a relater for isolated matters of fact as in the examples above, Boyle employed the testimony of artisans in arguments supporting his mechanical corpuscular theory against peripatetic explanations. Boyle's *An Essay about the Origins and Virtues of Gems* (1672) provides a useful picture

[36] Boyle to Oldenburg, 13 September 1673, *Correspondence of Henry Oldenburg,* 10:197.
[37] Ibid., 187.
[38] *Spring, Works,* 1:95.
[39] *Exp. Obs. Phys., Works,* 5:575.

of how he employed tradesmen's testimony, along with his own observations, to bolster theoretical explanations of nature.[40] For Boyle, previous speculation about the origin of precious stones was too general: Aristotle's "dry exaltation, (whether) fiery or firing, and more modern explanations that credit a fine mixing of earth and water" were both explications built upon "principles," which were "partly precarious, and partly insufficient, and perhaps also untrue" (514). As for imputing certain "virtues" (curative powers) to opaque stones, Boyle claimed not to be so dogmatic as some "moderns" who ignored the possibility that some stones might be infused with the right minerals as to have useful medicinal virtues. Nor did he condone those who were wholly accepting of these qualities among precious stones. Rather, he reservedly ascribed some virtues to gems, but not without "taking notice of nature's productions, and the trial whereto these considerations and observations lead me," which was "not to be expected from the followers of the peripatetick" (514). However, Boyle claimed that he would suit his discourse to the phenomena at hand without concern for whom he agreed or disagreed. Yet Boyle's purpose was also to promote a hypothesis: "I proposed this discourse but as a conjectural hypothesis, wherein I attempted to derive the origin of gems, and one of the main causes . . . of their qualities and virtues, from principles less remote and more intelligible than those of the peripateticks" (515). Boyle's "history" of the subject was to be both "natural and experimental" (515).

Boyle did not deem all the material from natural history on the subject of precious stones acceptable. Only a "tenth part" of what writers of "natural magik" as well as "men

[40] *Gems, Works,* vol. 3. Page references in the text apply to this work until otherwise noted.

of note" ascribed to precious stones held any truth; the rest was "unfit to be credited" (517). Yet Boyle was cautious not to throw away all suppositions, even the more fabulous ones, about the medicinal virtues of gems due to the strong attributions of credibility—skill, experience, reputation, personal knowledge—of the relaters: physicians of "so many ages," "divers eminent men," and "virtuosi of my own acquaintance" (517). Thus, he would not "indiscriminately reject" all the medicinal virtues that tradition had imparted on precious minerals; he would, however, assert only "one of the causes of those virtues ascribed to gems, which experience warrants to be real and true" (517). It was only after Boyle has fully explained the errors of method and explanation that have preceded his account that he finally delivered the particulars of his own hypothesis: "first, that many of these gems and medical stones either were once fluid bodies . . . or in part made up of such substances that were once fluid; and, secondly, that many of the real virtues of such stones may be probably derived from the mixture of metalline and other mineral substances, which (though unexpectedly) are usually incorporated with them" (517).

Whereas the subject of gems and minerals did not present Boyle with unobtainable personal experience, such as phenomena of the bottom of the sea or the extreme cold of the Arctic, it was a matter for which he thought proper to consult those who held expert, practical experience with precious stones and their characteristics under certain conditions. Thus, as in many other tracts, Boyle's essay consists of an intermingling of his own observations, experience, and experiments with the testimony of jewelers, miners, and engravers. For example, Boyle observed certain geometrical shapes

among different stones, such as triangular planes along rough cut diamonds in his mineral collection. To confirm his own observations of "angular and determinate shapes" in various diamonds he consulted an "expert jeweller that was also a traveller" (519). Boyle tied this phenomenon of crystallization to his conjectures about the fluid origins of gems by comparing these geometric shapes to those of nitre or common salt, which formed when their "corpuscles" coagulated upon evaporation of a liquid. To further this corpuscular connection between softer substances that crystallize and gems, he visited a "famous quarry" in order to find "some finer juice coagulated into some finer substances" (520). It seemed he discovered this substance inside a rock, which when broken, revealed both an evaporating fluid and the incumbent crystals. But this somewhat fabulous observation needed to be bolstered with the experience of miners: "And enquiring of an ancient digger, whether he had not sometimes met with a greater quantity of them? he told me that he had, and presented me with a great lump or mass made up of numerous congeries of soft crystals" (520).

Evidence for further attributes of gems also required the testimony of experience. That these "coalitions of particles may constitute solid and considerably hard bodies" was also evidenced by the way hard stones often cleft along parallel lines. Boyle claimed to have sometimes observed the grain in a blue stone from East-India and later "was answered by a skillful artist" that such stones usually slit along the lines of their grain. Boyle made his own microscopic observation of a diamond which showed him the "commissures of the flakes": "And for further satisfaction went to a couple of persons, whereof one was an eminent jeweller, and the other an artificer, whose trade was to cut

and polish diamonds, and they both assured me upon their repeated and constant experience" that it was nearly impossible to split a diamond across this grain (521). Further consultation of "the ancientest of these diamond cutters" taught that "sometimes he met with stones that eluded all his skill, and would by no means be split like the others . . . but would break in pieces" due to defects in the stone (522).

Much in Boyle's *Origins and Virtues of Gems* brings to bear the diverse criteria for credibility assessment that a natural philosopher could mobilize in order to bolster the truth of a relation—thereby strengthening the probability of his own observations and, thus, his discourse and hypothesis. Consequently, we see a need in Boyle to compound the credibility components of expert knowledge and experience with closeness to the event or the reasonableness of the matter being related, as assessed by Boyle's own knowledge of nature. A single claim, for example that softer gems of Germany and England are often found near "metalline veins," is best supported by "mineral writers of good credit, but also by eye-witnesses, and partly by [Boyle's] own observation"—implying Boyle's own trustworthiness and skillful knowledge (523-524). "And that mineral exhaltations may be met with in the bowels of the earth, is witnessed by the relation of divers credible persons, conversant about minerals, that affirm themselves to testify what they write upon their own observation, to which some things, that I had seen myself, did the more incline me to give credit" (558). Again we see practical, expert knowledge matched with the additional strength of closeness to the event and Boyle's own firsthand knowledge.

Elsewhere in the tract, however, the mobilization of multiple credibility components is absent. In the vein of his discoursing on the properties of gems and the narrative of his many observations and trials, the plausibility of the intermingled testimonial observations often rested solely upon the strength of practical experience or skillful knowledge and work. One example in particular goes directly at his hypothesis. Boyle attempted to cast doubt upon the accepted practice of identifying different precious stones based on the quality of their color. Rather, Boyle asserted that the mechanical principle of hardness was more determinate. Further, he averred that the color in gems originated from the presence of minerals and metals that had been infused into the stone while in its softer or fluid state. Boyle based his assertion of the arbitrariness of color for predicting stone type on the opinion and experiences of certain jewelers:

> That famous goldsmith Benvenuto Cellini . . . admonishes his readers that there are but one kind of rubies, that are naturally white (and not made so by art) which he proves degrees of hardness peculiar to rubies. And the same author elsewhere tells us of beryls, topazes, and amethysts, that are white . . . And it seems by what he says not far from that place, that the Italian jewellers did not look upon the tinctures of gems, as anything near to essential to them . . . The degree of hardness of rubies and sapphires is oftentimes so equal, that I knew an expert English jeweller, who for that only reason (for he knew not whence the difference of color might proceed) took rubies and sapphires to be of the same kind of stone. (524)

Boyle also demonstrated the importance of consulting the engraver's skills. "Skilful" here often seems to have denoted a combination of manual skill and specific knowledge. Boyle used the assertion that various "subterraneal fumes" could tincture even very hard gems to explain the odd tinge in a particular engraved sapphire. Boyle took the stone to "a skilful person of my acquaintance, by whom it had been engraven" for confirmation that the oddly streaked stone was indeed a sapphire (526). Boyle

reinforced this phenomenon with the relation of one "skilful, in Indian gems," who described "heterogeneous substance[s]" harbored in "grizolettes" (527). Elsewhere, Boyle's assertion of the importance of a "petrefcent liquor" from which stone crystals coagulate was confirmed "by some trial of it made by a skilful engraver of gems" (547).

Examples from *Origins and Virtues of Gems* also support the assertion that Boyle often used credibility as a rhetorical convenience. Often he floats between different components of credibility , choosing to emphasize those that fit the relater at hand, who has some relation pertinent to Boyle's own observation. In other sections of the tract he appears to build the credibility of a testimonial upon virtually nothing. Boyle claims to have seen fit to add something from an "anonymous, but curious" French author (528). The circumstances that he relates are not of his own firsthand knowledge but rather "from the mouth, as he affirms, of the famous late travellers he conversed with in divers places." The account seems best recommended by Boyle due merely to its being "the recentest I have seen in print" (528). The substance of the tract directly supports Boyle assertion that even hard gems such as (here) diamonds partake of the surrounding minerals in the location of their development: "So that if the earth be clean and somewhat sandy, the diamonds will be of good water; but if it be fat or black, or of another colour, they will have some tincture of it." That this anonymous source is included in his discourse no doubt is due to something more than the simple fact that its subject is the "estimation of gems." Boyle offers a better clue to its undeniably useful convenience in stating that it "tends highly to the confirmation of our hypothesis" (528).

Enhancers and Detractors

One cannot read Boyle for his methods of credibility establishment without noticing his frequent usage of physicians in these matters. In part, this must have resulted from a large number of these men involved in scientific matters and the frequency of Boyle's contact with them. However, Boyle almost certainly used them as important credibility builders because his readers within English society would have placed great stock in the word of the physician. Perhaps, for Boyle and his contemporaries this high degree of physician credibility emerged from a complicity of credibility components such as experience with and skill for observation along with education, learning, and a prominent social status.

It is not surprising, of course, that the testimony of physicians carried great weight in medical matters because they possessed both direct experience with and education in this specific area. In his *Origins and Virtues of Gems*, Boyle found direct reply to those who doubted his hypothesis—that gems were "impregnated" with minerals—with the testimony of physicians. Boyle confessed that he too would object to such claims, "but since upon the very credible testimony of eminent physicians and patients themselves of my own acquaintance, I find much less cause to disbelieve, than to assent to some matters of fact about the operations of gems; . . . such matters of fact do strongly argue, in the general, that a precious stone may have medical virtues."[41] Well-known among those who had dwelled in the southern plantations of the American colonies was the fruit, "which the planters call the prickled pear." That the redness of this fruit was "of so

[41] Ibid., 542.

penetrating a nature, that it passes from the stomach into the bladder, and then into the chamber-pot, with so little loss of its redness" was affirmed by "unsuspected eye-witnesses, and among them by a famous physician."[42] Similarly, Boyle named a "vegetable substance growing in Europe . . . which . . . is so violently operative, that a learned and famous modern physician relates" that only a half a gram of it could prove deadly.[43] These few examples, from the multitude scattered throughout his writing, especially his medical tracts, demonstrate a more mental variety of direct skill and experience as credibility enhancers.

What is further remarkable is how often Boyle used physicians' observations and relations for matters that did not directly pertain to medical phenomena. As discussed, this likely emanated from their general skills for observation as commensurate with their craft. For example, Boyle shared that a "very ingenious physician, that traveled much in the East Indies, and visited some islands in the South Sea . . . being asked of me some questions about the effects and changes of the air in those parts, related to me" that upon the cutting down of many clove trees ruined the quality of the air on one of the islands.[44] "Doctor N. answered me, that the winds he felt at Morocco were so very hot, that they were ready to stifle him, seeming to him like the steams and smoke coming out of the mouth of an oven."[45] Similarly, a "learned physician" that traveled to America assured Boyle that "those countries only have constant wind from the land in the night, which are furnished with hills: and therefore the Barbadoes wants such winds, because it has no

[42] *Specific Medicines, Works,* 5:81.
[43] Ibid., 82.
[44] *History of Air, Works,* 5:726.
[45] Ibid., 693.

hills."[46] Even on a metallurgical/alchemical subject, a "very learned and experienced physician" informed Boyle "that a few days before he had received [a visit] before in the night from a couple of strangers," one of whom was "(what they call) an adeptus," who showed the physician "a running mercury of a lovely green."[47] The physician further had the forethought to break up the mass of the mercury to confirm that the green tint ran through the whole substance. "These relations," wrote Boyle, "though they had come to me from less credible persons than those I received them from, I should not hastily have rejected."[48]

Examining Boyle's emphasis on skill and experience to build the credibility of testimony used in his natural philosophical tracts brings to light one other occasional phenomena: the tension created when a relater possessed certain credibility enhancers along with other potential detractors. Boyle's writing belies a seventeenth-century tension that emerged from using the word of an illiterate member of society when the matters he related emanated from practical skills or direct experience, though absent of general knowledgeability. For the deeply religious Boyle, the analogous relationship between the testimonial investigation into religious truths and into matters of fact about the natural world was taken for granted. Just as God may "make use of unpromising persons as his instruments" in divine matters, the experimental natural philosopher should not be surprised that he may increase his knowledge of nature "by what he learns from the observations and practices, even of mean (and perhaps of illiterate) persons (such as

[46] Ibid., 646.
[47] *Strange Reports, Works,* 5:609.
[48] Ibid., 609.

shepherds, plowmen, smiths, fowlers, etc.) because they are conversant with the works of nature."[49] The assumed conditions that made both instances worthy of credit were knowledge of what they delivered and honest relation. As early as the late 1640s Boyle kept company and correspondence with a group of practical-minded thinkers who were interested in experiment and the ways that knowledge gained from tradesmen could assist natural philosophy and society.[50] In several letters between Boyle and the pragmatic Samuel Hartlib (d. 1670), the two men wrote about instruments and inventions, as well as a proposed "History of the Trades" to be undertaken by William Petty (1623–1687).[51]

Yet a lack of general education could serve as an obvious detractor to credibility in seventeenth-century society. This is evident in the tension between the credibility components of general learning (in this case lacking) and specific knowledge in the following statement from Boyle: a philosopher, with all his "science," should easily improve husbandry, or any other art "resulting from the lame and unlearned observations and practices of such illiterate persons as gardeners, plowmen, and milkmaids."[52] Elsewhere, the truthfulness of the testimony from an illiterate person seems to have required weighing the plausibility of the matter being related. In the appendix to Boyle's *Christian Virtuoso*, Justinus tells Eusebius that should an "American fisherman" predict a

[49] *Christian Virtuoso, I, Works,* 5:529.
[50] Charles Webster, *The Great Instauration: Science, Medicine and Reform, 1626–1660* (New York: Holms and Meier), 57–67.
[51] R. E. W. Maddison, *The Life of the Honourable Robert Boyle, F.R.S.,* (London: Taylor and Francis; New York: Barnes and Noble, 1969), 71–72. Petty's work was never completed. Marie Boas Hall declared that scholars placed too much emphasis on asserting science's role in the improvement of technology. Instead, she perceived a sincere attitude within the Royal Society to examine the trades for what they could reveal about the workings of nature. See Marie Boas Hall, "Oldenburg, the Philosophical Transactions, and Technology," in *The Uses of Science in the Age of Newton,* ed. John G. Burke (Berkeley, Cal.: University of California Press, 1983), 21–43.
[52] *Usefulness, II, sect. 1, Works,* 1:64.

solar eclipse or claim to sail his vessel to a specific port in France or England, "his promises would be very unfit to be relied on, as being made by an illiterate fellow." On the other hand, should the same be claimed by a "European pilot, skilled in astronomy, and the art of navigation, it would be no credulity to think that he may perform his promises."[53]

Nevertheless, Boyle thought highly of the knowledge he gathered from less "learned" tradesmen and artisans with whom he interacted in England. Although Boyle clearly considered the benefits that natural philosophy imparted to trades to be the most significant, still, working with nature on a daily basis provided the tradesman with an enhanced credibility in specific matters that Boyle thought necessary for the prudent natural philosopher to consult. As early as his autobiography of the 1640s, Boyle demonstrated an awareness for the usefulness of "meaner persons": "And titular greatness is ever an impediment to the knowledge of many retired truths, that cannot be attained without familiarity with meaner persons, and such other condescensions."[54] Boyle further thanked the fortune of being "born in a Condition, that neither was high enough to prove a temptation to laziness; nor low enough to discourage" his aspiring.[55]

Boyle's essay "That the Goods of Mankind May Be Much Increased by the Naturalist's Insight into Trades" contained in the second part of his *Usefulness of*

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[53] *Christian Virtuoso, I, Appendix, Works,* 6:675. For the sake of tracing changing attitudes toward animals in England, Keith Thomas similarly describes a separation between learning and popular views. Increasingly, new discoveries of science and its more rigorous method revealed the ignorance of popular beliefs about nature to the men of science. See Keith Thomas, *Man and the Natural World: Changing Attitudes in England, 1500–1800* (New York and Oxford: Oxford University Press, 1983), 70–87.
[54] Boyle, "An Account of Philaretus During his Minority," *Works,* 1:xiii.
[55] Ibid., xiii.

Experimental Philosophy, provides the most concentrated explication on the subject.[56] Obviously, with a gentlemanly readership as his audience he wrote that "so oftentimes from those that have neither fine language nor fine cloaths to amuse him with, the naturalist may obtain informations" (443). After dealing a chastisement to "learned men" who disdained consulting the trades as a part of natural history, Boyle shared several reasons why the tradesmen's skills and experiences with nature were valuable. First, the tradesmen were "usually more diligent about the particular things they handle" (443). Because their livelihoods depended upon their productions, they were apt to pay closer attention for the sake of their profits. Second, "the want of subsistence, or of tools and accomodations" causes the tradesmen to become more "industrious and inventive" (444). They would thus discover new applications and attributes not likely to be taken notice of by others. Third, craftsmen often dealt with materials not written of by classical writers and used only in their shops, which necessitated the visitation of their places. Fourth, because tradesmen were unfamiliar with books, theories, and "opinions of the schools," they were apt to do things "by mechanical ways, which their own sagacity or casual experiments" discovered. Fifth, the observations made by tradesmen were more likely to be based on operations "more frequently repeated" than by those of an experimenter. Finally, through "unwelcome experience" craftsmen were likely to be aware of diverse circumstances—such as weather, materials, time, seasons—which affected the materials that they handled (445).

[56] *Usefulness, II, sect. 2, Works,* 3:442–456. Page references in the text apply to this work until otherwise noted.

These were the characteristics that Boyle considered the recommending factors for the consultation of tradesmen. That he bothered to explain these factors as part of his natural scientific writing demonstrates the importance that Boyle attributed to practical skill and experience for credibility and natural philosophy. That he criticized certain gentlemen for objecting to visit the locations where these personal traits held currency suggests that he believed the attribution of skill should transcend social boundaries and improve philosophical knowledge. Clearly, Boyle did not wish to confine them to the artisan classes. They served as the recommending credibility characteristics for tradesmen, physicians, and gentlemen—including himself. Whereas much of Boyle's writing reveals legalized descriptions and class awareness, I think Boyle's use of skill and experience as credibility components is better interpreted as a practical approach to testimony that pertained to specific phenomena in assorted fields, all of which Boyle thought natural philosophy encompassed.[57]

[57] "And certainly, true natural philosophy is so far from being a barren speculative knowledge, that physick, husbandry, and very many trades (as those of tanners, dyers, brewers, founders, etc.) are but corrolaries or applications of some few theorems of it." *Usefulness, II, sect. 1, Works,* 2:65.

CHAPTER 2

EXPERIMENTAL CONTINGENCIES

The practical procedures for experimentation were never self-evident. Robert Boyle and the Royal Society's Fellows developed the procedures of experimental knowledge-making largely through trial and error. While Francis Bacon's programmatic statements about empirical method and proper observation were numerous, he did very little practice himself. Thus, Bacon could offer only meager assistance concerning the many practical human contingencies associated with the every-day production of experiments—problems which Boyle and other experimental philosophers regularly contended. This is not to say that Boyle had no models of experimental activity from which to take inspiration. The work of prior "mechanists" whom Boyle admired, in particular Galileo (1564–1642), illustrated for Boyle the usefulness and wisdom of the experimental approach to nature. Boyle first became familiar with Galileo's work while on tour of the continent in 1642, and the Italian's telescopic observations that questioned Aristotelian cosmology impressed Boyle. He admired that Galileo often refrained from asserting grand philosophical systems, but focused instead on particular mechanical facts. Galileo's astronomical observations and his work on observed acceleration served as further examples of Boyle's anti-scholastic theme: experience could correct judgments

made with pure reason alone.[1] To avoid imagined theorizing, Boyle believed that one must work instead to gain nature's facts experimentally. But, even Galileo's admirable experimentation did not prepare Boyle for specific potentialities and hardships related to the process. Boyle admired Pascal's assertions about fluctuations in atmospheric pressure, but Boyle did not find his "experimental proofs" useful. Not only did Boyle question whether the Frenchman made the experiments himself; he also complained about the lack of circumstantial detail necessary for the effective replication of the experiments.[2] Boyle and the other virtuosi of the late seventeenth century worked out the practical details and coped with the many contingencies involved in experimentation for themselves.

The proper philosophical method for the production of matters of fact, also, was not self-evident. Steven Shapin and Simon Schaffer, for instance, question assumptions about the automatic acceptance of the experimental way of producing knowledge in the late seventeenth century.[3] Instead, they situate the new scientific method and other intellectual allegiances in a social and political context. Thus, for them, the dispute between Thomas Hobbes and Robert Boyle over the latter's air-pump experiments and their implications for the existence of a vacuum in nature were "embedded within the practical solution to the problem of social order."[4] Boyle's way, and that of the Royal Society, was one of collective, cooperative investigation. It implied compelled consent to the facts generated by corporate experimental activity. Hobbes criticized both the

[1] *Chrisitian Virtuoso, I, Works,* 5:127. Also, Sargent discusses Boyle's admiration of Galileo in matters of experiment in Sargent, "Learning from Experience," 59–60.
[2] *Hydrostatical Paradoxes, Works,* 2:745–746. Also see Ibid., 758.
[3] Shapin and Schaffer, *Leviathan and the Air-Pump,* chapter 1, especially 8–14.

collective certainty that experiments purportedly produced and the restrictive participation of the Royal Society that seemed to undermine the state.[5] As discussed earlier, Shapin additionally asserts that experimental practices reflected the transplantation of other, more familiar cultural norms, namely gentlemanly modes of discourse and the social spaces of genteel society.[6] These interpretations, while they certainly address, in part, some solutions to the internal practice of experiment, are highly focused upon the social, political, and cultural influences surrounding scientific development. Additional scholarly analyses stress more practical considerations accompanying the daily work of experimentation. For example, Rose-Mary Sargent does not dismiss the social dimensions of seventeenth-century scientific work entirely, but places emphasis on the influence of the "internal dynamics of [experimental] activity" itself upon relevant actors.[7] While developing a practical experimental program, Boyle learned from the practical activities of others, as well as the contingencies accompanying his own laboratory experience.

My focus on Boyle's awareness of skill and experience, their dissemination as qualities among relevant participants (both direct and indirect) and their impact on the practice of experimental activity assist understanding of this internal dynamic. Inescapable social implications do exist, however, in the form of social interaction; that is, the business of scientific investigation rested in part upon the work, and therefore the skill, of others in matters pertaining to both instrumental production and application. This

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[4] Ibid., 14.
[5] Ibid., especially chapter 4.
[6] Shapin, *Social History of Truth*; also see his "House of Experiment."
[7] Sargent, "Learning from Experience," 67.

chapter demonstrates that the contingencies of experimental practice through which Boyle developed a practical experimental program often resulted from the skill and experience of others due to the use of materials, instruments, and assistants. Also, I address how contingency applied to the popularization of science and experiment in England. Boyle shared some mishaps of his own experience, in part, for the sake of his general readership. He attempted to mitigate apprehension about experimental skill and curb genteel attitudes toward manual work.

Circumstances

> Peradventure it will not be impertinent to annex to the other circumstances, that have been already set down concerning this experiment, that it was made in winter, in weather neither frosty or rainy, about the change of the moon, and at a place whose latitude is near about 51 degrees and a half; for perhaps the force or pressure of the air may vary, according to the seasons of the year, the temperature of the weather, the elevation of the pole, or the phases of the moon; . . . and therefore it would not be amiss, if this experiment were carefully tried at several times and places, with a variety of circumstances.[8]

As part of the proper communication of experiments and their outcomes, Boyle thought it essential to describe even minute conditions surrounding many experiments—in the above case, anything that might affect the properties of the air. Obviously, he was aware that the miniscule might alter data and results. But besides the atmospheric conditions and their effects on the properties of the air, Boyle expressed concern over many hidden qualities in the materials employed in experiments. In the first of his "Two Essays Concerning the Unsuccessfulness of Experiments" (1661), Boyle narrowed the causes of wavering experimental outcomes to unnoticeable properties within the

[8] *Spring, Works,* 1:73.

materials employed, which he elaborated in the essay, and the errors committed in handling those materials.[9] Put simply, some experiments did not "succeed" because they were tried at one time with "genuine" materials and at other times with "sophisticated" ones (319). Pharmaceuticals, salts, metals, chemical "menstruums," gems, and even urine, varied greatly enough in quality, strength, and unseen impurities as to account for disparities in experimental outcomes (319–329). This sensitivity for the details surrounding experiments, however, also arose in connection to his hesitancy to espouse grand philosophical "systems"—for which he was critical of others. One could not prudently build such grand philosophical schemes on few experiments because the precise outcomes of these experiments often reflected unseen but significant contingencies. Therefore, Boyle warned against building "considerable super-structures, either theoretical or practical," that relied too much on few experiments that dealt with minerals. Many who had looked upon a fortunate mineral experiment later met disappointment when the seemingly same procedures produced unwanted results (348–349).

These faulty materials often reflected human deceit or lack of skill. Boyle declared that it should not surprise anyone familiar with the "drugs and simples" sold in the apothecary shops that these compounds were often adulterated "by the fraudulent avarice of the sellers" (319). For instance, he complained of "little creatures" that he found in vinegar purchased for experiments. He was thus forced to distill his own so as to ensure purity (320). After sending to a chemist for some "spirit of salt" that the chemist

[9] "Two Essays Concerning the Unsuccessfulness of Experiments," in *Certain Physiological Essays, Works,*

himself prepared, Boyle declared that the product produced "scarce a credible quantity" of what he desired, nor "pure enough, to perform what we had expected"(320). Attempting to rectify the problem with yet even a more skillful chemist, Boyle met with failure again, as the spirit of salt was both "sophisticated" with other impurities and too weak compared to that which he had known to be "skilfully and sincerely drawn" (320). In another instance, Boyle expressed that a "heedless" miner, aiming only at obtaining a certain quantity of metal, may have "neither the design, nor perhaps the skill" to separate the heterogeneous matter from his ore. The material, then sold to a merchant or chemist, might look as it should, but it could contain unknown ingredients (322). Even urine was subject to important circumstances that the skillful experimenter should heed. Tradesmen and chemists, Boyle claimed, often made use of it without considering whether it was recent or aged, or whether derived from healthy young men (rich in "volatile salts") or sickly, old persons (328). In short, "there is a great difference to be found among many things prepared by art, that pass under the same general name" (329).

Only Human

As we have seen, there existed many experimental contingencies related to the fluctuating properties of materials and their unskillful production. But what of those contingencies that resulted directly from human skill—or lack thereof—among actors within the experimental scene? These circumstances surrounded the production of scientific instruments, the application of those instruments in the experimental setting by experimenters and assistants, experimenters' conceptualization of experiments, and the

1:318–353. Following page references apply to this work until otherwise noted.

perception of their results. Skill and experience figured as constantly expressed concerns in Boyle's experimental tracts because the successfulness of so much experimental work depended upon the capabilities of so many actors.[10]

Continuing from where the extended quote that opened this chapter left off, Boyle shared yet other circumstances that bore upon a constant theme in his experimental tracts: the bemoaning of insufficient precise instruments and apparatus. In this case, he would like very much to gauge exactly the fluctuations in the pressure of the air (according to stated variables) using "cylinders of several diameters, exquisitely fitted with suckers" and other devices. No shortcomings existed with the conceiving of the instruments that the task required, but rather with their production. "These, and diverse other such things," could have been tried with this equipment "if we could get tubes so accurately blown and drawn, that the cavity were perfectly cylindrical."[11] In the absence of ideal instruments and materials he made do with what human skill could produce.

Fortunately, as Boyle expressed, skillful knowledge of physics could improve the production of superior instrumentation. In elaborating the usefulness of the "mechanical disciplines" to natural philosophy, Boyle discussed, in part, how these disciplines assisted naturalists in producing "instruments and tools" that aided observations and trials.[12] "One good mechanical contrivance may be as considerable as many particular experiments . . .

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[10] Shapin and Schaffer interpret the philosophical importance of Boyle's emphasis on contingencies. They explain that unsuccessfulness could be a "positive resource" for validating the experimental program as it would suggest problems that reside with materials or an apparatus without jeopardizing a particular hypothesis (such as the spring of the air): *Leviathan and the Air-Pump,* 185.

[11] *Spring, Works,* 1:173.

[12] "Of the Usefulness of Mechanical Disciplines to Natural Philosophy," in *Usefulness, II, sect. 2,Works,* 3:435–441; by "mechanicks," Boyle referred to "those disciplines that consist of the applications of pure mathematicks to produce or modify motion in inferior bodies": Ibid., 435.

and even slight and obvious" little inventions were greatly significant, according to Boyle.[13] For example, thanks to the mechanical arts, useful tiny brass pieces, which skillful workmen originally told Boyle could not be made, had been devised and employed in his experiments.

Boyle also acknowledged defective human observation. These inaccurate observations when "made by the help of material instruments framed by the hands and tools of men, cannot but in diverse cases be subject to some, if not many, imperfections upon their [the instruments'] account."[14] The example he provided for this point was the telescope. Astronomers of his day, he complained, gave so many accounts of "spots and more shining parts" on the surface of the sun that they led readers to presume them to always be there. Yet months of observations with superior scopes and conditions revealed but few instances to him. Then, having consulted "a most ingenious professor of astronomy, excellently well furnished with dioptrical glasses," Boyle learned that this man, too, saw but few with his "good" telescopes.[15] The implication is that those astronomers who spoke of the spots and flares with such regularity had been misled by inferior instruments. Varying qualities of instruments, Boyle suggested, also explained "differing supputations" among modern and ancient writers concerning the "circuit of the terrestrial globe, . . . the distance and bigness of the fixed stars," the planets, and the

[13] Ibid., 440.
[14] *Certain Physiological Essays, Works,* 1:347.
[15] Ibid., 347.

height of mountains. Besides the "unequal skill" of the several observers, Boyle imputed discrepancies also to the greater and lesser exactness of the instruments employed.[16]

Sometimes Boyle's statements about insufficient instrumentation suggested a lack of skill associated with the age during which he lived.[17] Trades simply had not advanced far enough to provide the technological precision required for the purposes at hand. Such seems the case with the devices needed to measure the globe, stars, planets, and mountains mentioned above. In the *General History of Air* (1692), Boyle wrote of perfecting accurate observations with "several large and exact thermometers, placed in several rooms." However, the situation was "much to be lamented" as "no considerable improvements" had "been made by any man, of these glasses, either in our own country, or any where else, since their first invention."[18] Boyle wrote at length elsewhere about the "deficiencies" of thermometers and the caution necessary for their usage.[19] Even with the recent advances of "sealed weather-glasses" and the variety of fluids employed as a medium, Boyle still recommended the "prudence" of compounding multiple methods for measuring cold.[20]

Other instances suggest problems of skill that were local. London, of course, provided a wider selection of skilled and experienced artisans: "I learned them from the

[16] Ibid., 347–348. It is important to point out, however, that overall Boyle was very praising of telescopes, purchasing some of the best of his era for himself or the Society.
[17] *Usefulness, II, sect. 2, Works,* 3:397. Here Boyle declared that the practices of artificers varied at different times and different places.
[18] *History of Air, Works,* 5:643. Boyle also adds particular complaints as to the diameter of the cylinders and their gradation.
[19] *Cold, Works,* 2:489–499.
[20] Ibid., 499.

best artificers (especially those of London) I had opportunity to converse with."[21] Naturally, depending upon where in England Boyle conducted his work, he would find artisans of varying usefulness and materials of differing qualities. This was especially true when working outside London. For example, short of paper, Boyle was unfortunately in a place where he could get no "white leaves, to supply a fine table-book." Nor could he find any tradesman in the area that knew "the way of making so much as ordinary table-books"; so he improvised one himself from materials in an apothecary's shop.[22] Due to problems with locality, Boyle also disclaimed some of his less ideal experiments addressing the nature of cold. Being "reduced to make many of those experiments in a village," he did not have "instruments and other assistance to [his] wish."[23] He listed the materials that the local artisans could not provide, including "conveniently shaped glasses," instruments to seal them, necessary "ingredients," weather glasses, and "tender scales."[24]

Sometimes, however, the skills of the artisans in his specific location proved fortuitous. For instance, after proceeding with particular air-pump experiments as far as he could, Boyle was lucky to meet "an artificer not altogether unskillful," and he directed the man to make a brass plate to better cover the top of the glass receiver. Luckily, "by the help of which contrivances we persecuted the newly related experiment much farther than we could do before."[25] Similarly, he shared that he was in a city with both good materials and workmen and thus he requisitioned a bowl of "well seasoned wood" that he

[21] *Usefulness, II, sect. 2, Works,* 3:397.
[22] Ibid., 418.
[23] *Cold, Works,* 2:472.
[24] Ibid., 472.

needed in order to proceed with an experiment.[26] Whether the talents of the local artisans proved disastrous or beneficial, they certainly occupied Boyle's thoughts. The contrasting abilities of so many artisans impressed on his conscious a practical concern for how varying capabilities impacted his experimental trials.

Additionally, Boyle attributed the sometimes inconsistent products of artificers to unexplainable and imperceptible "little accidents."[27] These problems, while hard to ascribe, often hindered artisans from doing that which they usually could do successfully. As an example, Boyle related his dealings with an "eminently skilled" artisan in a glass-house, whom he employed to make some glass vessels that required more than the usual dexterity in their creation. The artisan was not able to concoct the right mixture of "sand and fixt salt" and so asked Boyle to come another day when he might repair his "unluckiness." Upon returning, Boyle found again that the man could not make his materials behave as they would normally—this time stained with blue and yellow colors. He did not discredit the artisan's skill in this case but attributed the outcome to unpredictable hidden qualities of materials. Boyle tied this to a larger experimental point: philosophers and chemists should not wonder, then, that sometimes an expected experimental event will not succeed more than once, and even after repeated trials.[28]

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[25] *Spring, 1st Continuation, Works,* 3:275.
[26] Ibid., 280.
[27] *Certain Physiological Essays, Works,* 1:339.
[28] Ibid., 339.

Although Bacon and his later followers recommended direct hands-on experience, throughout his life Boyle employed a large number of assistants.[29] Importantly, the skill with which these assistants applied the many apparatus of experimental practice varied significantly. Boyle's writing are full of instances in which experiments went awry on account of clumsy execution or "technical ineptitude."[30] This should be expected as many of the experiments Boyle directed, for example, those using the air-pump, required a skillful operator or some degree of technical knowledge. As we will see later in this chapter, using the device required skillful remedies to prevent the escape or intrusion of the air at many different points. A very different kind of experiment, animal vivisection, directed by Boyle or the Royal Society, also required specialized skills—not to mention a strong constitution—especially when the relationship among the air, the heart, and the lungs was the subject of examination. Experimenters had to possess a good knowledge of anatomy in order to perform proper incisions, and skill was required to keep the animal alive during the procedure.[31]

Besides applying his skills to the manipulation of experiments, the experimentalist could make unskillful perceptions of outcomes while overseeing the trials. Many of Boyle's famous air-pump experiments involve barometric observations of the air's removal and effects upon mercury and other fluids. Boyle explained that, in part,

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[29] Shapin, *Social History of Truth,* 374. Shapin asserts that Boyle often performed relatively little experimental work himself. This was especially true, he claims, after 1670 because of various health problems, and he relied increasingly on paid assistants (375).

[30] Ibid., 389. Shapin relates that the journals of the early Royal Society recorded "constant dissatisfaction with the skill and reliability of its employees." Robert Iliffe describes Robert Hookes similar complaints about the "incompetence" of operators and instrument makers while employed at the Society in the late 1650s and early 60s. See Iliffe, "Material Doubts," 288.

discrepancies between measured levels among England and other countries involved discrepancies of the increments of the English inch when compared to those used abroad, a problem overlooked by less experienced naturalists. Of course, differences also resulted "by reason of the negligence or incogitancy of most that make the experiment."[32] Closer inspection of a tube of mercury revealed many small bubbles that Boyle thought might account for varying results. Thus, to assist other attempters of the experiment, Boyle suggested "expedients to hinder the intrusion of the air."[33] This presumption concerning the intrusion of tiny bubbles during similar experiments upon the compression of water led Boyle to refrain from drawing any certain conclusions about the "elastical power" of water. Boyle knew that an experienced observer considered unseen contingencies that may exist behind apparent effects: "So apt are we to be misled, even by experiments themselves, into mistakes, when either we consider not that most effects may proceed from various causes, or mind only those circumstances of our experiment, which seem to comply with our preconceived hypothesis or conjectures."[34] Oversights could also occur while attempting to gauge the specific gravity of mercury and water. Skillful observations of natural materials required expert knowledge of the intricacies of these substances. Boyle warned that even with precise scales, an experimenter might commit an oversight if he failed to perceive that the surface of water in a vessel was concave, while that of the

[31] Anita Guerrini, "The Ethics of Animal Experimentation in Seventeenth-Century England," *Journal of the History of Ideas* 50, no. 3 (1989): 391–407. Boyle himself often participated in these vivisections (397).
[32] *Spring, Works,* 1:38.
[33] Ibid., 38–39.
[34] Ibid., 47.

quicksilver convex.[35] These slight variations could effect the amount of each placed on the scale and, therefore, their relative weights.

From experience Boyle knew that often the various contingencies necessitated the alteration or abandonment of an experiment.[36] Sometimes he delayed experiments until the contingencies could be overcome. For example, in making an attempt at igniting gunpowder in the evacuated receiver, the "external air" intruded throughout many trials so that the one was abandoned for another. In a second trial, this time with a stouter receiver, the glass proved too thick, and the rays from the magnifying glass refracted too much to discharge the powder. The potential usefulness of the experiment with gunpowder required that they attempt the experiment again, but not until "the season is more favourable. . . . In the meantime we shall pass on to other experiments."[37] While conducting certain experiments addressing effects of cold, the lack of proper materials forced him to "leave experiments untried" in some cases and in others to prosecute them only in "the best manner that was practicable by the accommodations I was then able to procure."[38] As Boyle described his situation: "when I write of experimental matters, in places where I cannot have workmen, nor instruments fit for my turn, I must be content to

[35] Ibid., 88.
[36] Importantly, however, these accidents sometimes provided positive results. Just as navigators, forced by violent storms from their intended courses, often discovered unknown regions which eventually proved advantageous to them, "so in philosophical trials, those unexpected accidents, that defeat our endeavors, do sometimes cast us upon new discoveries of much greater advantage," than the expected success of the experiment would have provided: *Certain Physiological Essays, Works,* 1:353.
[37] *Spring, Works,* 1:32.
[38] *Cold, Works,* 2:472.

vary my experiments accordingly, and suit them to the accommodations I am confined to."[39]

Boyle's experimental essays concerning the properties of the air discovered with the air-pump provide an instructive encapsulation of the above topics—the skills of the artisan and experimenter, location, and instruments. Defense of the experimental program against its critics was tied up in defending the integrity of the air-pump itself.[40] Critics, especially Thomas Hobbes, could use the pump's existing imperfections to assail the validity of the matters of fact gained by its use. This explains Boyle's preoccupation with explaining the contingencies of particular experiments or bemoaning the unavailability of sound materials. The value of knowledge gained from an experimental project often rested on the quality of the available instruments, which, in turn, depended upon the skills of artificers. Hobbes and other critics pointed to many avenues through which the air might leak into the pump, calling into question the complete removal of the air from the glass receiver.

The construction of the pump itself involved a great amount of toil. Finding an already existing German model too full of defects, Boyle directed Robert Hooke and an assistant to create a more useful device. Contingencies related to production of the glass receiver, from which the air was evacuated, placed limits on its experimental use. Due to limited glass blowers' skills, the receiver that Boyle settled for was considerably smaller than what he desired. Boyle explained in *New Experiments Physico-Mechanical Touching the Spring and Weight of the Air* (1660) that "the glass-men professed

[39] Ibid., 472.

themselves unable to blow a larger [vessel], of such a thickness and shape as was requisite to our purpose"; so Boyle accepted one that was merely "less unfit than any of the rest."[41] In addition to difficulties posed by the receiver, the apparatus required many precisely fitted pieces for its efficacious use. In fact, the large number of parts necessary for the original machine and the intricacies of their workings necessitated three full pages of description, in addition to a labeled diagram (7–10). But this initial description was only the beginning of the explication required, and all the air-pump experiments scattered throughout his works contain generous mention of the functioning of this or that part and their value in keeping out the air.

Thus, throughout the descriptions of the numerous individual experiments, one inescapable theme was this air-leakage. Efforts were not completely successful, and "in spite of all our care and diligence we never were able totally to exhaust the receiver, or keep it, when it was almost empty, any considerable time, from leaking more or less" (10). As one of several modifications that Boyle and his assistants made to their device, they had smaller, thinner receivers blown, along with smaller stop-cocks—which kept air out between each pump—fashioned in order to "keep out the air much more perfectly" (25). Nonetheless, the problem persisted, according to Boyle's description of a particularly complicated mercury experiment (Experiment XVII): "And thus continuing the labour of the pumping for about a quarter of an hour, we found ourselves unable to bring the quicksilver in the tube totally to subside; because, when the receiver was considerably emptied of its air, and consequently that little that remained grown unable to

[40] Shapin and Schaffer, *Leviathan and the Air-Pump,* chapters 2, 4, and 5.

resist the irruption of the external, that air would (in spight of whatever we could do) press in at some little avenue or other" (34). And later with smaller glass vessels, they still could not prevent a little of the external air from intruding. Thus, they were unable to fulfill the mission of the experiment—to "make observations accurate enough, concerning the measures of the quicksilver's descent, to reduce them into any hypothesis" (35). Boyle had to settle upon "almost quite empty," but fortunately that was "enough to enable men to discover hitherto unobserved phenomena of nature" (10).

Related to leakage, of course, was the glass receiver itself and, thus, the glass-blower's art. Obviously, the quality of the glass used for the observation vessel was yet another circumstance of the experiments that was contingent upon the skill of others. In his *Continuation of New Experiments Physico-Mechanical Touching the Spring and Weight of the Air, Part I* (1669), we see that the problem persisted, as in the original experiments.[42] Boyle complained in the preface that the experiments were not made in London, and thus the theme of location and materials is present here also. Consistent with similar complaints, Boyle bemoaned that "want of a glass-house, and other accommodations reduced me to make my trials . . . in the best way I could then and there put into practice."[43] Thankfully, not every small crack of particularly round receivers rendered them useless. The exsuction of air simply forced the seam along the crack to close. On the other hand, some cracks were less cooperative and, "because receivers fit for our turn are more easily cracked than procured," had to be mended. Such

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[41] *Spring, Works,* 1:7. Page references in the text apply to this work until otherwise noted.
[42] *Spring, 1st Continuation, Works,* vol. 3. For example, Boyle was "hindered by want of receivers tall and capacious enough" for his needs: Ibid., 270.
[43] Ibid., 177.

contingencies of imperfect glass receivers necessitated unusually creative, but skillful, remedies:

> Plaster was made of good quick lime finely poudered, and nimbly ground with a pestle in a mortar, with a quantity . . . of scrapings of cheese and a little fair water . . . which, when the ingredients are esquisitely incorporated, will have a strong and stinking smell. . . . But if your Lordship had seen, how we mended with it receivers even for the most subtle chymical spirits, you would scarce wonder at the service it hath done in our pneumatical glass.[44]

Yet other problems with location and proper materials figured largely in the first *Continuation*. Experiment XXXVII, for instance, required air-tight bellows. He found a tradesmen to make them, but, though the man was "otherwise dexterous," his trade was not bellows production—nor was it any other man's in town.[45] In spite of Boyle's "oiling the leather and choking the seams with good cement," the air managed to pass through some imperceptible cranny. Apparently, in other instances the problem of inadequate instruments necessitated altering the experimental approach. For his attempts in Experiment XLVII to measure the air's spring, Boyle "despair[ed] to get a syringe as I desired in the place where I then was [and so] bethought myself of another way" (267). So with "much ado" he managed to find a man skilled in "turning" and had some brass cylinders fitted (268). Still, Boyle did not seem to think that the results at the end of the experiment demonstrated exactness, owing to the imperfections of the cylinder's production: "I cannot but think, that if a cylinder, or other convenient instrument, exactly tight, can be procured, the spring of an aerial cylinder will appear to be greater than we found it by the forgoing trials" (270).

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[44] *Spring, Works,* 1:26.

For the Royal Society's critics these potentialities called into question the philosophical appropriateness of their experimental method.[46] Boyle's disputations with Thomas Hobbes in the matter of the air-pump experiments involved much more than just a disagreement about particular matters of fact that Boyle claimed he produced, or even the philosophical ramifications of a vacuum in nature. Also underlying their quarrel were opposing ideas about the proper production of knowledge. Boyle criticized Hobbes for "not being content to manage himself and his way of treating physical matters, but has been pleased to speak very slightingly of experimentarian philosophers (as he stiles them) in general, and, which is worse, to disparage the making of elaborate experiments."[47] When Boyle defended himself against Hobbes' criticisms, he defended the experimental program itself and thus part of the foundation upon which it lay—skillful manipulation of nature and ingenuity. As Shapin and Schaffer astutely explain, when Hobbes leveled the charge of "ingenuity" or "engine philosophy," he was denigrating cleverness and inventiveness and implying that experimental philosophy rested upon the intellectual processes of mechanics and artificers.[48] Boyle and his colleagues at the Royal Society, on the other hand, celebrated ingenuity without Hobbes' attachment of a seventeenth-century stigma.

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[45] *Spring, 1st Continuation, Works,* 3:249. Page references in the text apply to this work until otherwise noted.
[46] Shapin and Schaffer go so far as to claim that once leakage became a publicly visible trouble, it threatened to destroy the experimental program itself. See Shapin and Schaffer, *Leviathan and the Air-Pump,* 170–171.
[47] Boyle, "Animadversions Upon Mr Hobbes's Problemata De Vacuo," in *Hidden Qualities of Air, Works,* 4: 105.
[48] Shapin and Schaffer, *Leviathan and the Air-Pump,* 129–130.

Skill, Contingencies, and the Popularization of Science

Boyle labored to include information about failed experiments in his work for a number of reasons—potential unseen circumstances, assistance for replication, and protection of his credibility. But disclosure of experimental failure also served to alleviate the anxieties of novice experimenters by showing that failures could occur in spite of the application of proper experimental skills. Here, I will demonstrate that Boyle considered part of the work of popularizing experimental practice involved allaying the gentlemanly apprehension concerning the skillful manual labor that experimentalism required by sharing his own "failures" in the laboratory.

Boyle addressed many of his experimental tracts to his nephew Richard—referred to as "Pyrophilus" throughout his works—son of his sister Katharine, Lady Ranelagh. Similarly, his air-pump tracts were written in the form of a letter to another nephew, Charles, Lord Dungarvan, son of his eldest brother, the second Earl of Cork. Thus, the tone throughout many of his works was that of a dialogue of advice for these young aspiring gentlemen experimenters. But to consider his experimental tracts merely personal communications—as opposed to public—is short-sighted. As I examine more fully in the next chapter, Boyle diligently saw to the mass publication of his works and attempted a writing style that would appeal to a broad audience. However, I do not believe we should dismiss this missive-format as mere convention either. Boyle's addressing Pyrophilus and Charles in the second person gave his tracts a certain intimacy, not simply as a fond uncle to his nephews as individuals, but to his nephews as

representatives of a kind—genteel, novice experimenters.[49] In his *New Experiments Physico-Mechanical*, he explained that he wrote to Charles "since it may highly conduce to the advancement of that experimental philosophy . . . to endear it to hopeful persons of your quality, who may accomplish many things . . . by being able to employ the presents of fortune in the search of the mysteries of nature."[50] Notice Boyle here referred to a plurality of his nephew's peers. Later in the same tract, Boyle described why he shared details of failed experiments. Partly, he did so that "what we endeavored in vain, may be performed by your Lordship, or some other Virtuoso, that shall have" better equipment and a more "fortuitous" day.[51] In his *Experiments and Considerations Touching Colours* (1664), Boyle asked to be excused for the length of some experiments by disclaiming that they were written "so as to teach a young gentleman to make them."[52]

To allay the fears of the young gentleman for the pursuit of experimental philosophy, Boyle forewarned Pyrophilus about the contingencies that may lead to the unsuccessfulness of particular experiments. Even those experiments that were communicated by "candid authors or undistrusted eye witnesses, may upon further trial, disappoint your expectation."[53] In the same essay he recommended "watchfulness in observing experiments, and wariness in relying on them; but not at all to such a despondency of mind" that might deter the young gentleman from making them.[54] As

[49] John T. Harwood describes Pyrophilus as a "fictionalized 'Every Reader.'": Harwood, "Science Writing and Writing Science: Boyle and Rhetorical Theory," in *Robert Boyle Reconsidered,* ed. Michael Hunter (Cambridge: Cambridge University Press, 1994), 48.
[50] *Spring, Works,* 1:6.
[51] Ibid., 32.
[52] *Colours, Works,* 1:663.
[53] *Certain Physiological Essays, Works,* 1:318–319.
[54] Ibid., 352.

was his tendency, Boyle emphasized the point with an analogy. The physician, he explained, does not abandon his profession if some patients do not recover as expected; nor does the husbandman forsake cultivating the ground should storms occasionally wreck his crops. For that matter, just as navigators were occasionally blown off course only to discover new lands that prove advantageous to them, so too in philosophical trials "those unexpected accidents" sometimes cast the experimenter upon new discoveries.[55]

But to minimize the chances of this "unsuccessfulness" Boyle consistently advertised particular experiments that did not require advanced skill and experience so the novice experimenter could perform them more auspiciously. In his *Origin of Forms and Qualities* (1666), Boyle stated broadly of the experiments contained therein that they "do not require much time, much charge, or much skill."[56] Addressing Pyrophilus, he wrote that the third experiment of the set could most easily be put into practice.[57] One of the recommending qualities of his essays concerning the usefulness of experimental philosophy was that they contained particulars that were of "easy trial, or immediate use," so as to persuade a "greater number of differing readers."[58] He continued by saying that the "variety and easiness I have aimed at in the experiments" may invite the "generality of readers, though of different inclinations" to "addict" themselves to the study of experimental philosophy.[59] Finally, explaining the content of some of his experimental essays overall, Boyle informed Pyrophilus—"but a beginner in

[55] Ibid., 352-353.
[56] *Forms and Qualities, Works,* 3:75.
[57] Ibid., 83.
[58] *Usefulness, II, sect. 2,Works,* 3:395.
[59] Ibid., 400.

experimental learning"—that he made use of "seemingly slight" experiments because they were the "more easily and cheaply tried."[60]

Boyle hoped that their "easiness" would not disappoint the novice experimenter's expectations and that early success would "incourage [him] to make trial also of more nice and difficult experiments."[61] Boyle was clearly trying to nudge Pyrophilus toward experimental activity by insuring that he gain confidence from initial successes, but the goal was to move him on into more difficult and skillful experiments. At first Boyle had "taken care by the truth of the experiments I have delivered, to secure your success." But some particulars had been omitted, Boyle told Pyrophilus, thereby creating a "necessity laid on you to exercise your own industry, and thereby increase your experience."[62] Clearly, Boyle attempted a sort of graduated process—simple successes might lead to complicated activity that required more experimental skills.

Boyle further recommended the general use of experiment among readers by alleviating apprehensions about mechanical skill with complicated devices. In doing so, he suggested two levels of experiment: those experiments that required precise instruments and skill with their use, and those experiments that were easily made but nonetheless provided useful information to natural philosophy. Those critics who demanded "of attempters the very best contrivances" had provided "no small hindrance" to the advancement of natural philosophy. Too many "would be attempters" heeded the judgment of these critics.[63] Boyle asserted further that whereas in some experiments the

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[60] *Certain Physiological Essays, Works,* 1:306.
[61] Ibid., 306.
[62] Ibid., 316.
[63] *Spring, 1st Continuation, Works,* 3:177.

exactness of fine instruments was useful and necessary, other experiments advance knowledge "by the most easy and compendius ways deviseable."[64] Not being particularly "dexterous" or ingenious at contriving complicated experiments was for Boyle "no sure argument" that a man had not a "solid knowledge" of his activities.[65] For even those "without any peculiar gift at mechanical contrivances" served natural philosophy by conceiving experiments and proposing ways of bringing them to trial, "which, though perhaps not the most skillful or expeditious, are yet sufficient and practicable."[66] Additionally, Boyle consistently stressed the benefits provided by the "most common observations" for the improvement of natural philosophy.[67] Boyle "would have no man, who hath leisure, opportunity, and time, to think it a slight thing to busy himself in collecting observations of this nature" (weather and temperature).[68]

The popularity of scientific activity within England had, of course, some relationship to the availability of instrumentation. Some modern scholars see the emergence of a "scientific support community" when they study late seventeenth-century England.[69] Boyle himself made comment about the many shops in London that supplied English gentlemen "skilled in dioptrics and happy at mechanical contrivances" with

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[64] Ibid., 177.
[65] Ibid., 177.
[66] Ibid., 178.
[67] *History of Air, Works,* 5:642.
[68] Ibid., 642. See also, *Cold, Works,* 2:473: "The history of nature would make too slow a progress, if it were presumed, that none but geometers and mechanicians should employ themselves about writing any part of that history."
[69] A. D. C. Simpson, "Robert Hooke and Practical Optics: Technical Support at a Scientific Frontier," in *Robert Hooke: New Studies,* eds. Michael Hunter and Simon Schaffer (Woodbridge, England: Boydell Press, 1989), 36.

microscopes and telescopes.[70] Samuel Pepys' diary evidences one gentleman's interest in a variety of scientific instruments; Pepys was the proud owner (and frequent user) of a twelve-foot telescope purchased from the London manufacturer Richard Reeve.[71] Those "ingenious men" living outside of London should not despair, however, that they "cannot furnish themselves with the best instruments and accommodations, nor enjoy the assistance of the skilfullest artificers."[72] He explained that sometimes "ounces and inches" served the purpose of measurement without need for "lines or grains" because a great number of physical phenomena do not require "mathematical exactness."[73]

In chapter 3 I detail Boyle's recommended perceptive and communicative skills that he found essential for the prudent practice of experimental philosophy. Because he placed such high demands upon those who practiced experiment, his desire for the popular practice of experimentation throughout general society seems problematic. A conflict might appear to have existed between his stringent expectations for experimental skills, on the one hand, and his systematic promotion of experimental science in English society on the other. Yet his statements concerning these requisite skills seem to apply more to dedicated chemists, scholastics, or natural philosophers than to the average

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[70] *Usefulness, II, Works,* 3:139, cited in Simpson, "Robert Hooke," 36. Simpson relates that Boyle bought a long telescope for the Royal Society from Richard Reeve, who sold advanced telescopes and microscopes in England during the 1660s (38–39). Also see *Usefulness, II, sect. 2, Works,* 3:400.

[71] Samuel Pepys, 6–7 August, 8 August, and 19 August 1666, *The Diary of Samuel Pepys,* eds. Robert Latham and William Matthews, 11 vols. (Berkeley, Cal.: University of California Press, 1970–1983), 7:238, 240, 254. The index (vol. 11), under the listings "Scientific and Mathematical Instruments" and "Science and Mathematics," suggests that Pepys witnessed a variety of experiments and used a number of scientific apparatus (254–255). Also see Marjorie-Hope Nicolson, *Pepys' Diary and the New Science* (Charlottesville, Va.: University Press of Virginia, 1965). Nicolson asserts that it was not the Royal Society that developed an interest latent in Pepys, but rather growing tendencies of his age, which was becoming science conscious.

[72] *Cold, Works,* 2:473.

[73] Ibid., 473.

gentleman curious about performing his own experiments. As discussed above, Boyle's writings demonstrate that he was quite conscientious of likely wide-ranging levels of experimental skill and experience among his readers. But his statements also belie a stigma attached to the manipulative work of experiment, which he sought to erode.

Modern scholars cast attention to the potential conflicts between the gentlemanly attitudes and experimental philosophy. As a knowledge-gaining system, it involved the work of the mind, but also that of the hand. Steven Pumphrey analyzes the early efforts of the early Royal Society and concludes that the accomplishments that gained the Society its reputation were performed largely by middle-class assistants whom the genteel majority "did not value as experimental philosophers," but rather as mechanists.[74] Because these experimental laborers—including Robert Hooke and Denis Papin—received payment for their services and performed work that "demanded manual skill and dirty, sweaty labour," they maintained a lower status.[75] Class awareness and attitudes toward physical work are implicit in Shapin and Schaffer's analysis of Hobbes suggestion that an "engine philosophy" produced an inferior sort of knowledge because it relied upon the intellectual processes of artificers and mechanics. This was a "serious imputation" in Restoration society.[76] Whereas Michael Hunter's work does not directly address gentlemanly attitudes toward manual skill, his examinations of the Society's membership demonstrates that it fell somewhat short of its expressed goals of inclusion for all levels of society. Therefore, he concludes that interest in science was found mostly

[74] Pumphrey, "Who Did the Work," 139.
[75] Ibid., 132.
[76] Shapin and Schaffer, *Leviathan and the Air-Pump,* chapter 4, esp. 129–130.

among the landed gentry—active merchants had little time or interest and artisans felt the intellectual topics of science out of their reach.[77] That participation in the Society predominately reflected the higher social strata—as Hunter's work suggests—entailed that many inexperienced, but willing, gentlemen certainly confronted the prospect of manual experimental labor. This seems especially true in light of Steven Shapin's assertion that the proposed entrant into an experimental scene need only to have been "a gentleman of quality and merit" without regard to "any particular technical competences."[78]

Boyle's efforts included campaigning to raise the esteem in which the upper classes held this manipulative work that they witnessed. He did this by showing the necessity of manipulation for cajoling knowledge from nature. For example, "without the manual and artificial operation of the gardener" certain natural effects could never have been produced. Sometimes we must "put [nature] out of her course by the strength and skill of man" in order to create "the most instructive condition, wherein we can behold her." (443) Boyle's *Hydrostatical Paradoxes* (1666) was a published version "of a discourse pronounced before an assembly," the Royal Society; consequently, he referred to "gentlemen now present."[79] During the description of a particularly toilsome barometric experiment in the work, he told the assembly that "one must not be discouraged by not being able, at the first or second time, to suck up oil of turpentine to the due height, and stop it with one's finger from relapsing; but one must try again and

[77] Hunter, *Science and Society,* 60–62, 70–71, 73–74. Hunter, *The Royal Society,* chapter 1.
[78] Shapin, "House of Experiment," 388–389.
[79] *Hydrostatical Paradoxes, Works,* 2:738–739; 756.

again, and again."[80] He continued that "for beginners" the use of the finger, though not the shortest way was "safe and good." [81]

Concluding this section, it is worth noting that Boyle's advocacy of experimental work often seems an argument directed at scholastics who emphasized a more rational approach to knowledge-production. But to what extent should we consider, instead, that his statements were directed not only at philosophical rivals but also at societal attitudes toward manual labor? Examining Boyle's writing to promote the activities of experiment, it is easy to infer seventeenth-century sensitivities toward manual labor or any gentlemanly association with the skills of tradesmen. Boyle's lengthy recommendation for a connection between philosophy and the trades alone suggests a society in need of convincing. Whereas most of the essays under the general heading *Some Considerations Touching the Usefulness of Experimental Natural Philosophy* addressed the ways in which natural philosophy benefits other facets of learning, Boyle also, of course, directed the philosopher toward consulting the trades. Such a relationship benefited both "the naturalist's knowledge, and the melioration of those mechanical arts."[82] He admonished those who possessed "neglect [of] and contempt" for this interaction simply because the "men from whom it may be learned, are illiterate mechanicks, and the things that are exhibited are works of art and not of nature" (442). Boyle's expressed purpose in writing his *Usefulness* tracts, he told Pyrophilus, was to "invite you, and assist you to invite other ingenious men, to a farther study of nature" (422). He wished to impart "reasonable

[80] Ibid., 753.
[81] Ibid., 753.
[82] *Usefulness, II, sect. 2,Works,* 3:442. Page references in the text apply to this work until otherwise noted.

inducements" for the discovery of the "fruits" to be gained from the practice of natural philosophy, "if it be industriously and skillfully cultivated" (422).

Boyle's awareness of the impact of human skill resulted from his experiences with the contingencies of experimental practice. This was so because the materials, instrumentation, and apparatus necessary for scientific investigation involved the skillful production of artisans and their application by assistants. The impact of these ancillary, though highly significant, personnel often necessitated the modification and sometimes the abandonment of particular experiments. Yet Boyle still had to defend the experimental method, which incorporated elaborate instruments and devices, and thus the skillful productions of artisans and tradesmen. Furthermore, Boyle's awareness of the contingencies owing to experimental skill also influenced his writing directed at the general reading audience. Thus, while defending skill and ingenuity as proper to knowledge production, he simultaneously downplayed the importance of experimental experience and skill for the novice experimenter and attempted to curb gentlemanly attitudes towards the manual work of experiment.

CHAPTER 3

REQUISITE SKILLS

One approach to the scientific revolution of the seventeenth century is to present a polar contrast between the ancients and the moderns. According to this view, before the seventeenth century began, the state of knowledge about the world was bound up in speculative systems, which were not based upon any real "modern" scientific method, per se, but a sort of common-sense logic applied to the superficial appearances of nature. Dissatisfaction with the science of the "schools" had already begun in the sixteenth century and grew during the early seventeenth among those who practiced the emerging science of the day. Francis Bacon, of course, elaborated the empirical, inductive approach that influenced much of the experimental work of the Royal Society in England later in the century. For his part, Bacon denigrated the scholastics of the Middle Ages for limiting their minds to the parroting of syllogisms passed down from the ancients, and he lamented how little learning had advanced since antiquity.[1] Some men had been doing a sort of experimental work since the Renaissance, but for Bacon it was too haphazard, unstructured, and spoiled by theoretical preconceptions. Philosophers were to put aside

[1] Butterfield, Herbert, *The Origins of Modern Science, 1300–1800,* revised edition, (New York and London: Free Press, 1957), 111.

grand systems and speculations about final causes in nature until a thorough, properly organized natural and experimental history were constructed.[2]

I do not wish to go over well-worn ground but rather to focus where Boyle's thoughts on the philosophical skills of the natural philosopher reflect his own abundant anti-ancient rhetoric. Like other writers before him, many of Boyle's quarrels with the scholastics were theoretical. For instance, he denounced their adherence to explanatory properties and qualities—color, fluidity, coldness—as part of a perverted version of Aristotle's doctrine of "substantial forms," which Boyle found overly mystical. He also disputed that matter could be neatly divided into the four elements of earth, air, water, and fire. Boyle had similar theoretical problems with certain chemists and alchemists, who espoused what he believed to be the wrong-minded doctrines of either the Peripatetic school or Paracelsus. They thought, similarly, that matter could be reduced to a few basic principles, such as sulfur, salt, and mercury.[3] Against these rival theories that addressed the ordering of nature, Boyle asserted his corpuscular mechanical philosophy. These disagreements between rival explanatory constructs represent constant themes in the writings of Boyle and his contemporaries. But I illuminate a different aspect of Boyle's attacks on the scholastics and certain chemists. As part of his campaign to explode rival theories, Boyle did often emphasize the fallacy of their speculations, but he also questioned the shortcomings of their practical philosophical skills, and in so doing illuminated those practical mental skills that accompanied what was for him the right-

[2] Ibid., 113.
[3] Boyle, "Of the Imperfections of the Chymists' Doctrine of Qualities," in *Mechanical Origin of Qualities, Works,* 4:273.

minded experimental natural philosophy. These various skills can be grouped under the general categories of perception and communication.

Acceptable degrees of probability rested upon the effective perception and communication of phenomena, which in turn necessitated avoiding certain human fallibilities. Francis Bacon sought to create a new method of scientific investigation that involved carefully refining and analyzing sense data, which then served as matters of fact for his inductive method. Importantly, Bacon sought to achieve scientific certitude with this method. Accordingly, Boyle and other fellows of the Royal Society constantly reported on matters of fact that had been established through wide-ranging experiments, observations, and reports. Wisely, scholars have noted that there were a number of "non-Baconian elements" in the work of the Society's members—Boyle, Hooke, Wilkins, Sprat, and Glanvill.[4] Instead of scientific certitude, they worked under assumptions of differing degrees of probability; avoiding Bacon's "forms" behind nature and his axioms, they commonly replaced them with mere descriptions of natural phenomena; and, whereas Bacon largely denounced hypotheses, mid seventeenth-century natural philosophers sometimes employed them.[5] Nevertheless, for Boyle and his colleagues Bacon's statements about human fallibility—his famous Idols—were significant in their natural philosophy and during their experimental work.[6] Boyle's ideal philosophical skills of perception involved issues closely related to Bacon's Idols of the Tribe, which

[4] Shapiro, *Probability and Certainty,* 67; I. B. Cohen, *Revolution in Science* (Cambridge, Mass. and London: Belknap Press of Harvard University Press, 1985), 149; Butterfield, *Origins,* 138–140.
[5] Shapiro, *Probability and Certainty,* 68.
[6] Glanvill, for instance, parroted Bacon's idols when he described the deceptiveness of the senses, the fallacies of our imaginations, and the influence that "natural disposition," custom, and education "have over

included the fallibility of the human senses, and the Idols of the Cave, or defects of individuals owing to their education and customs. Boyle's statements about the proper manner of writing about experimental outcomes took on issues of Bacon's Idols of the Marketplace, which included the inherent defects of words. For Boyle, proper practice of the new science necessitated honing skills essential for correcting these human defects.

Employment in the Workshop of the World

Boyle's belief in certain physical and mental skills as requisite qualities of the dedicated natural philosopher went hand-in-hand with his conception of a mechanical universe, itself a product of a divine master artificer. Boyle's mechanistic conception of the world was too bound up in his religiosity for scholars to dismiss the persona of the "humble artisan" as mere rhetorical window-dressing.[7] The many works of nature revealed God's wisdom and skills. "The contrivance of every animal, and especially of the human body, is so curious and exquisite, that it is almost impossible for any body . . . to imagine or conceive, how much excellent workmanship is displayed in that admirable engine." Even the "meanest" living things created by God greatly surpassed what "human heads and hands can boast of."[8]

Twentieth-century scholars have written much about natural philosophy and seventeenth-century English society. As discussed, often the crux of these examinations concerns the uses of the new science to bolster religious (or often social and political)

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our Understandings." See Joseph Glanvill, *Essays on Several Important Subjects in Philosophy and Religion* (New York and London: Johnson Reprint Corp., 1970), 18–22.
[7] Shapin and Schaffer, *Leviathan and the Air-Pump*, 130.
[8] *High Veneration, Works,* 5:136.

positions.[9] I will not support or dismiss any of these various assertions here. Instead, I wish to emphasize that, in addition to their importance for illustrating that Boyle's mechanical world was compatible with his creationism and God's constant providence, the lengthy mechanical analogies scattered copiously throughout Boyle's writing show also the importance of skill and experience to his rhetoric. They were, therefore, essential to his promotion of the experimental natural philosophy. We get the impression that, for Boyle, humans, while the most sublime of the skillful creations, were also admiring guests in the showroom of the divine workshop: "First then, when our virtuoso sees how many, and how various, and oftentimes how strange, and how admirable structures, instincts, and other artifices, the wise Opificer hath furnished even brutes and plants withal" it will persuade him of so "wise an Agent, who has at command so many differing and excellent methods and tools."[10] Boyle reserved derision for those, including certain "arrogant Peripateticks," who claimed to explicate the beginning of things without giving credit to God's workmanship.[11]

For Boyle, experimental natural philosophy entailed work. Charges of and lamentations about humankind's laziness are common sidebars in Boyle's discourses. That many vulgar errors of tradition could be debunked "if men had not so lazy a

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[9] Richard Westfall, *Science and Religion in Seventeenth-Century England* (New Haven: Yale University Press, 1997); J. R. Jacob, *Robert Boyle and the English Revolution*; M. Jacob, *The Newtonians and the English Revolution*; and M. Jacob, *The Radical Enlightenment.* All three works assert brands of science closely tied to religious outlooks and/or political allegiances.

[10] *Christian Virtuoso, I, Works,* 5:521. Also see John Ray, *Wisdom of God,* 8. Ray similarly celebrated the skillful creation of nature: "For . . . as it argues and manifests more skill by far in an Artificer to be able to frame both Clocks and watches, and Pumps, and Mills, and Granadoes and Rockets . . . so the Almighty discovers more of his Wisdom in forming such a vast multitude of different sorts of Creatures."

[11] *Usefulness, I, Works,* 2:36.

curiosity, as not to try" for themselves experimental tests recurs throughout his writings.[12] He declared that anyone who has taken notice of the usefulness of experiments to philosophy, has experienced the "difficulty, trouble, and charge of making them."[13] Many show more leisure for the writing of "disputations" than the conduct of experiment, "which, to be performed as it ought to be, doth, in many cases, besides some dexterity to be gained but by practice, requires some more diligence."[14] In part, this was one aspect of the anti-scholastic rhetoric of the day. Compared to the relatively easy natural philosophy taught in the schools, the experimental natural philosophy was "difficult and toilsome."[15] Boyle was aware that the Peripatetics claimed to ground their system upon both reason and experience, similar to adherents of the mechanical philosophy. But they contented themselves with experiences that nature provided as a matter of course. Experimental philosophers, on the other hand, "enlarge[d] their experience by trials purposefully devised" to which they conformed their opinions.[16]

The plausibility of one's conclusions required numerous experimental trials. As discussed along with the contingencies of experiment, Boyle knew that many factors effected the outcome of an experiment. A common theme that applied to the skillful use of experimental data was that the wary natural philosopher avoid theory-building upon few experiments. One should try experiments very carefully and more than once before

[12] *Cold, Works,* 2:513. See also, *Usefulness, I, Works,* 2:46–47: "But there is so much difference among men, as to their faculty of framing distinct notions of things, and through men's partiality to laziness" that many reject a notion simply because they have no mind to assent to it.
[13] *Defence, Works,* 1:122.
[14] Ibid., 22.
[15] *Usefulness, I, Works,* 2:5.
[16] *Christian Virtuoso, I, Works,* 5:513–514.

building "superstructures."[17] Boyle seemed to feel sorry for those naturalists who explicated the "causes of things" or the "mysteries of nature" only to have their statements confused by some later discovery in nature.[18] He compared this to what happens to the counterfeiters of coins. A false coin could fool one individual test, whatever its kind, but it is unlikely that the coin will pass a compounded variety of tests. So too might a theory agree with one experiment or another, but it was wiser to consult a "competent number of them."[19] Similarly, Boyle distinguished between real and imagined experiments. As discussed, he intimated that Pascal never made certain key experiments himself, but rather speculated on their processes and outcomes. Boyle asserted that from experience, he knew experiments that were "but speculatively" true often miscarried in practice.[20]

It is important to understand, however, that Boyle did not intend for pure experience to supersede reason. The reasoning ability for Boyle, importantly, was the most supreme of the attributes that God imparted to man, although Boyle believed that God intentionally placed limits upon it.[21] In his *Reconcileableness of Specific Medicines to the Corpuscular Philosophy* (1685), Boyle claimed that he derived his belief in "specifics" for three reasons.[22] First, he enlisted the testimonies of "learned physicians,

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[17] *Certain Physiological Essays, Works,* 1:348–349: The example he provided was of those who find varying results from what would appear to be the same mineral experiments. See also, *Defence, Works,* 1:121.
[18] Ibid., 307–308. He does not provide an example.
[19] Ibid., 308.
[20] *Hydrostatical Paradoxes, Works,* 2:758–759.
[21] Jan W. Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge: Cambridge University Press, 1997). Wojcik argues, in part, that Boyle's views on reason's limits affected his conception of the proper goals and methodology of the new natural philosophy.
[22] *Specific Medicines, Works,* vol. 5; by "specifics" Boyle meant remedies from particular sources that have very specific curing effects—for example a specific plant for a particular snake's bite.

both ancient and modern"; the second inducement he ascribed to the "parity of reason"; and the third was from experience, both his own and those of others.[23] Experience was but an "assistant"—albeit an essential one—to reason.[24] Experience assisted by supplying information to reason's understanding, but "understanding remains still the judge, and has the power or the right to make use of the testimonies, that are presented to it." Thus, instead of the expression that experience corrects reason, Boyle declared it more proper to say that reason itself, "upon the information of experience, corrects the judgments she has made before."[25]

Yet reason unassisted by experience could mislead the philosopher. A "skilful considerer" of God's "exquisitely framed, and admirably managed works" often discovered truths which he previously thought false when he considered them "but upon grounds of incompetently informed reason."[26] The planet Venus, for example, appeared to be a totally luminous disc until the telescope revealed that the planet cycles from full to wane as does the moon.[27] Elsewhere, Boyle warned of the danger that arose when some chemists and physicians erroneously reason certain outcomes of experimental mixing of medicinal compounds.[28] Experience showed, instead, many unforeseen consequences that occurred due to the many hidden qualities and compounds that resulted from "untried ways of compositions."[29] While the untried mixtures may, luckily, prove advantageous, they may also prove harmful as medicines. Furthermore, Boyle criticized the mistakes

[23] Ibid., 78–81.
[24] *Christian Virtuoso, I, Works,* 5:539.
[25] Ibid., 539.
[26] Ibid., 537.
[27] Ibid., 537.
[28] *Exp. Obs. Physicae, Works,* 5:582.

belonging to physicians who for centuries ignored experience and held to ancient principles for sake of tradition. He lamented the number of women who had died during the letting of blood for the purpose of causing a miscarriage, which "experience hath assured us" would have been rescued by "a discreet phlebotomy."[30]

But rewards awaited the devotee of experimental philosophy who was willing to apply his skillful attention to nature's workings. A virtuoso who "by manifold and curious experiments searches deep into the nature of things, has great and peculiar advantages to discover and observe the excellent fabric of the world" compared to those who "are not both attentive and skilful."[31] For theology, too, the experimenter may discover "deep and unobvious truths."[32] Boyle charged that the libertine wits of his day declined to study all truths in the same sustained and serious manner of the experimental philosopher, and so dwelled only upon superficial and obvious truths. In an interesting analogy of skillful activity, Boyle likened the superficial wit to an "ordinary swimmer, who can reach but such things as float upon the water," while an experimental philosopher resembled a "skilful diver that . . . [can] make his way to the very bottom of it, and thence fetch up pearl's, corals, and other precious things, that in those depths lie concealed from other men's sight and reach."[33]

The skillful mental work of the natural philosopher required some mental calisthenics. As a component of his pious devotion Boyle practiced "occasional

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[29] Ibid., 582.
[30] *Usefulness, II, sect. 1, Works,* 2:65.
[31] *Christian Virtuoso, I, Works,* 5:518; see also, Ibid., 516: "There are a great many more curious and excellent tokens and effects of divine artifice, in the hidden and innermost recesses of them; and these are not to be discovered by the perfunctory looks of oscitant or unskillful beholders."
[32] Ibid., 524.

meditations," musings about religion, society, and nature.[34] That the mind should stay on constant guard against idleness and evil thoughts made their practice important. But besides their religious benefits, the mental work of these reflections also honed the skills of the natural philosopher. According to Boyle, occasional meditations strengthened the reasoning faculties of the practitioner, allowing for better observations of the world. Besides a "readiness and subtilty in conceiving things," one also learned to express observations with "quickness and neatness."[35] Similarly, Lotte Mulligan argues that Robert Hooke used his diary for the improvement of his natural philosophical acumen. Hooke's diary writing could be used to hone his skills—including his memory—as a student of nature while also providing a "self-knowledge of a kind that would guard against errors resulting from faults in the human perceptual" ability.[36] Writing the diary was one way to improve his performance as a philosopher and natural historian by making him aware of Bacon's "idols" that could distort performance.[37]

Perception

Skillful perception was one requisite of the experimental natural philosopher, but skillful use of the senses involved knowing their limitation as mere "outward instruments

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[33] Ibid., 524.
[34] "A Discourse Touching Occasional Meditations," in *Occasional Reflections, Works,* 2:335–358.
[35] Ibid., 343–346 (quote, 346). Boyle's work seemed to have an effect upon Richard Baxter. In a letter to Boyle, he thanked him for some books, including Boyle's "Meditations and Reflections." He reflected Boyle's rhetoric of a skillful approach to nature: "God . . . shewed me that my studys must not be play, but effective, practicall, serious worke. Baxter saw it as the "difference betwixte a pleasant easie dreame & a waking working knowledge. He that has well learnt in the Alphabet of his Physicks . . . has laid such a foundation for a holy life, as all the reason in the world is never able to overthrow." Baxter to Boyle, 14 June 1665, *Calendar and Correspondence of Richard Baxter,* eds. N. H. Keeble and Geoffrey F. Nuttall, 2 vols. (Oxford: Clarendon Press, 1991), no. 720.
[36] Lotte Mulligan, "Self Scrutiny and the Study of Nature: Robert Hooke's Diary as Natural History," *Journal of British Studies* 35 (July 1996): 312, 333.

of the soul," not as actual judges of phenomena.[38] Boyle listed sight among one of many potential human defects. Wary philosophers did not "trust their eye to teach them the nature of the visible object." Sight often could deceive, as a square tower may appear round from a distance or a straight stick crooked under water. Boyle continued that thoughtful employment of the senses involved "not only reason, but philosophy."[39]

Implicitly, this skillful perception stemmed from proper philosophy—that is, the corpuscular, mechanical hypothesis. Education in various fields enhanced the skill of one's perceptions. The works of nature "require, as well as deserve, the most attentive and prying inspection of inquisitive and well-instructed considerers." Boyle continued that many "admirable things" escaped the "vulgar eye." The "clearer light" a man has—competent knowledge of anatomy, optics, cosmography, mechanics, and chemistry—the more he may discover of "unobvious esquisiteness."[40] In the second part of the *Christian Virtuoso* (1690), Boyle added that God, in framing the "great machine of the world," included so many intricacies that it could not be discerned but by "the curious contemplator, furnished with considerable skill in mathematicks, physicks, anatomy, opticks, and diverse other disciplines." Those that examine the phenomena of nature with the "most fixed and piercing eyes" would discover more and more "in proportion to the measure of his attention and philosophical knowledge."[41] In answering critics of his air-pump experiments, Boyle wrote that most men, except "some able mathematicians and

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[37] Ibid., 315.
[38] *Christian Virtuoso, I, Works,* 5:539.
[39] Ibid., 539.
[40] Ibid., 516.
[41] *Christian Virtuoso, II, Works,* 6:719; also, Ibid., 763: "A skillful naturalist . . . by the help of anatomy, chemistry, hydrostaticks . . . will be able to disclose many wonderful things."

very few other contemplative men," did not comprehend his doctrine concerning the properties of the air. These mistakes of understanding resulted "perhaps for want of skill in Hydrostaticks," and thus they did not understand the theory that they attacked.[42]

Boyle believed that, among philosophers, the experimental philosopher alone possessed the skill to discern the excellent workings of God. While philosophers of the schools sometimes gave account of God's magnificence, their too shallow approach to nature prevented them from basing their homage upon the many intricacies of particular creations.[43] While some evidence of God's wisdom was so obvious that the "superficial philosopher" may infer it, the experimental philosopher alone could discern the full extent of God's wisdom in nature. For it was only by a "diligent and skilful scrutiny of the works of God" that one discovered "that the author of nature is 'wonderful in counsel, and excellent in working.'"[44] Besides the evidence of his wisdom and goodness that remained upon the "surfaces" of his works, "there are a great many more . . . in the hidden and innermost recesses of them." These "require, as well as deserve, the most attentive and prying inspection of inquisitive and well-instructed considerers."[45]

A variety of Boyle's copious metaphors clearly demonstrate his preoccupation with experimental philosophy's connection to skillful work of perception and understanding. Throughout, denotations of skill that ride the fine line between applied labor and mental acumen (as discussed in the introduction) are amply evident. For example, he frequently depicted the world through the metaphor of the written text. By

[42] *Defence, Works,* 1:120.
[43] *Christian Virtuoso, I, Works,* 5:517.
[44] Ibid., 517.
[45] Ibid., 516.

representing the world as a book, the natural philosopher necessarily became the trained reader, literate in its language; that it is a language requiring much skill is evident from Boyle's phrasing. John Harwood, examining Boyle's use of metaphor, elaborates that "the text of nature, as [Boyle] called it, was 'God's stenography,' hieroglyphics, or God's epistle; God was the writing master."[46] The "carelessness, or ignorance of men" prevented them from discovering the "signatures of the divine Author's wisdom and goodness" that a more "skilful and attentive survey" would reveal.[47]

Under the topic of credibility I demonstrated that Boyle would consult with the practical skills of the tradesman for information about phenomena with which they had daily experience. Yet the skillful and experienced natural philosopher conversely supplied benefits to practitioners of trades. Tradesmen, he expressed, dealt with only a few of "nature's productions" and so had only observed the more obvious qualities of their materials.[48] What they knew was gained more from the application of "manual dexterity" than from "any diligent or accurate search."[49] Natural philosophical knowledge, on the other hand, provided enhanced perception. Boyle explained that while a butcher may kill and cut into pieces sheep and oxen a thousand times, he may not discover all the "wonderful contrivance , that a good anatomist will, by skillfully dissecting the same animals."[50] Boyle thought it "a disparagement to a philosopher" if he could not "improve the precepts of an art, resulting from the lame and unlearned

[46] Harwood, "Science Writing," 50-51; Harwood quotes Boyle from the following: *Usefulness, I, Works,* 2:63; *Occasional Reflections, Works,* 2:349; and *Excellence of Theology, Works,* 4:77.
[47] *Christian Virtuoso, II, Works,* 6:785–86.
[48] *Usefulness, II, sect. 2, Works,* 3:421; similar sentiment in Ibid., 446.
[49] Ibid., 421.
[50] *Christian Virtuoso, II, Works,* 6:786.

observations and practices of such illiterate persons as gardeners, plowmen, and milkmaids."[51] As a skillful natural philosopher, Boyle employed one technique in particular that superceded the otherwise skillful and experienced testimony of an expert artisan. Throughout his tracts, he demonstrated great pride in his ability to measure the "specifick gravity" of substances by testing their relative weights in water ("hydrostatically"). For example, Boyle disagreed with the statement of one jeweller who asserted diamonds to be the heaviest of all minerals. It did not agree with Boyle's own "experience," having tried the "weight of an uncut diamond hydrostatically," a way "more exact than any other of the known ways can be."[52]

Conversely, it should be noted that Boyle also implied that a desire for prudent observation often dictated a suspension of knowledge, for education comprised one of Bacon's defects of human observation. In other words, philosophical expectations often obscured or misdirected the perception of experimental outcomes. Thus, a certain empty-mindedness can lend enhanced probability to the observation of an experimental outcome. A good example comes from Boyle's *Dialogue on the Transmutation and Melioration of Metals*, in which the character Heliodorus applauds Pyrophilus' use of witnesses because it is "easy for even a clear-sighted Experimenter to over-look some important circumstance, that a far less skilful by-stander may take notice of." Pyrophilus claims to have told the witnesses only a little information about the expected outcome since people "are inclined to think that they *do see* that happen which think they *should*

[51] *Usefulness, II, sect. 1, Works,* 2:64.
[52] *Gems, Works,* 3:529; see also Ibid., 536.

see happen."[53] Still, whether resulting from the honing of skills or from the suspension of knowledge, clearly Boyle considered accurate perception and observation to be significant skills for the experimental natural philosopher.

Communication

Properly communicating the perceived phenomena derived from experimental natural philosophy, as well as wisely relating the observations borrowed from others, involved certain practical considerations. Boyle's concern for skill extended also to the promotion of communicative techniques he thought fit for the experimental natural philosopher. While these were suggestions for proper practice, they also served to further points in Boyle's written works that advanced experiment. These skills involved both mental acumen in framing discourse, as well as very practical considerations related to publication.

Modern scholars have written much about the programmatic statements from the seventeenth century concerning the promotion of language revision. Many intellectual disciplines of the seventeenth century—science, philosophy, history, and law—moved toward a simplified, stream-lined literary presentation. Vague terms, concepts, and doctrines were to be avoided; in the rhetoric of the seventeenth century, plain language was preferred. Thomas Sprat, the spokesman for the early Royal Society and its program of science, denounced "fine speaking" and metaphor, calling for a natural, simple way of

[53] *Transmutation,* in Principe, *Aspiring Adept,* 282. Similarly, *Spring, Works,* 1:47: "So apt are we to be misled, even by experiments themselves, into mistakes, when either we consider not that most effects may proceed from various causes, or mind only those circumstances of the experiment, which seem to comply with our preconceived hypothesis or conjectures."

speaking, like that of artisans and merchants. Barbara Shapiro traces this trend across disciplines throughout the seventeenth century, including the vehement, overt attacks by virtuosi on poetic language, metaphor, and rhetorical flourishes.[54]

Recent scholarly work on Boyle, however, somewhat complicates the rhetoric of simplicity during the late seventeenth century. For example, John T. Harwood targets Boyle's ambition to be a literary influence in both England and Europe.[55] Towards this literary program Harwood recognizes deliberate strategies that Boyle employed to fashion his literary identity, including seeing to Latin translations of his works and adopting a "variety of social roles and personae" in his writing.[56] Most importantly, he argues that metaphor was significant to Boyle's understanding of nature and was part of the literary style, which he used to win an audience for natural philosophy. Consistent with this approach to Boyle's literary techniques, Lawrence Principe traces the development of Boyle's early writing style during the 1640s and charts influences imparted on and received from scientific writing.[57] Principe finds that, in spite of Boyle's "love-hate" attitude toward it, "the French heroic romance (in its heyday during the 1630s and 1640s) and related popular literary currents were the most powerful single influence on the young Boyle's writing."[58] Further, this influence was not passive but an intentional adoption designed to address rhetorical needs. Similarly, James Paradis asserts that Boyle took the French familiar essay, conceived by Montaigne, as the model for his

[54] Shapiro, *Probability and Certainty,* 256–257.
[55] Harwood, "Science Writing."
[56] Ibid., 39.
[57] Lawrence Principe, "Virtuous Romance and Romantic Virtuoso: The Shaping of Robert Boyle's Literary Style," *Journal of the History of Ideas* 56, no. 3 (July 1995): 377–398.
[58] Ibid., 379.

experimental essay.[59] He argues that Boyle shifted its focus from internal, personal observation and experience to the external, physical world.[60]

Scholarly focus on Boyle's statements about clear writing and the practitioners of chemistry are even more germane to our examination of his communicative skills. Principe points out that in Boyle's chemical tracts attacks against ambiguous and obscure terms are the sharpest of all Boyle's criticisms toward "vulgar" chemists—a feature that is hard to miss in his chemical writing.[61] Boyle, he claims, intentionally distinguished the understandable secrecy of alchemical adepts, toward which he was condoning, from the communicative incoherence and ambiguity of other chemists, namely Paracelsians, laborants, pharmacists, and textbook writers. Jan Golinski takes a unique look at the characteristic interpretation that assumes the influence of natural philosophy on chemistry during the seventeenth century.[62] By explicating overlooked literary themes in the chemical tradition itself, she attempts to make the commonly accepted relationship between the two "problematic." While Golinski declares that some scholars have identified an increased use of allegorical style in chemical tracts during the century, other chemists of the Paracelsian tradition often declared their wish to write openly and clearly.

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[59] James Paradis, "Montaigne, Boyle, and the Essay of Experience," in *One Culture: Essays in Science and Literature,* ed. George Levine (Madison, Wisc.: University of Wisconsin Press, 1987).

[60] Likewise, Mulligan argues that Robert Hooke used his diary "as an attempt to record the self as an exotic object," in a manner similar to obtaining an objective truth about an "external object": Mulligan, "Hooke's Diary," 312, 315. Shapin and Schaffer also, of course, discuss the importance of "literary technology" to the promotion and development of the experimental program at the Royal Society. As part of the virtual witnessing that underpinned formal experimental practice, communication of experiments entailed including many circumstances surrounding particular experiments: Shapin and Schaffer, *Leviathan and the Air-Pump,* chapter 2, especially 60–64.

[61] Principe, *Aspiring Adept,* 48–50, 56.

[62] Jan Golinski, "Chemistry in the Scientific Revolution: Problems of Language and Communication," in *Reappraisals of the Scientific Revolution,* eds. David C. Lindberg and Robert S. Westman (Cambridge: Cambridge University Press, 1990), 367–396.

Further, as the textbook tradition developed, "formal devices were incorporated that ensured greater clarity of description and more systematic nomenclature."[63] Thus, when Boyle called for clarity and strict use of terms in the writing of chemistry, he was himself "using one of the most common rhetorical tropes of that very tradition" he criticized.[64] Antonio Clericuzio counters that Golinski misses one point of Boyle's criticism. Boyle's dissatisfaction, Clericuzio claims, was not directed at a unclear descriptions of experimental facts, but rather at certain chemists who "failed to provide the philosophical interpretation of experiments."[65]

This variety of interpretation about Boyle's literary influences and techniques converge in a significant point of agreement: they bring to light the fact that Boyle consciously and deliberately employed the content and form of language as tools. Throughout his tracts—chemical, experimental, and religious—he recommends, both directly and by example, the skillful application of literary devices. His own employment of these devices served both to win proponents to the experimental program and to demonstrate the equipment requisite for induction into the seventeenth-century natural philosophy. Just as skill was essential for a rewarding approach to the "reading" of God's skillful creation, so too should the writer apply it in order to bring the reader closer to an understanding of phenomena.

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[63] Ibid., 375.
[64] Ibid., 386. For a discussion of similar contradictory phenomena in Hooke's writing, see Mulligan, "Hooke's Diary," 336–337.
[65] Antonio Clericuzio, "Carneades and the Chemists: A Study of *The Sceptical Chemist* and Its Impact on Seventeenth-Century Chemistry," in *Robert Boyle Reconsidered,* ed. Michael Hunter (Cambridge: Cambridge University Press, 1994), 82.

Skillful use of metaphor is one of Boyle's obvious and deliberate writing tools. Harwood has argued effectively that Boyle often used figurative language, especially the metaphor, as aids to the comprehension of the natural world's intricacies: "The Royal Society needed both microscopes and metaphors," and Boyle promoted the use of both "instruments."[66] He demonstrates that both mechanical philosophy and the corpuscular hypothesis were "heavily dependent on figurative language for their meaning."[67] Boyle considered it part of his task to advance the new philosophy with the best possible metaphors for subjects the reader could not observe first hand.

Ambiguous terminology and unclear description could hinder both the reader's understanding and the experimental philosopher's skillful probings. Boyle commonly complained about the Peripatetics' tendency to describe nature in terms of substantial forms and real qualities. The shortcomings of this tradition for Boyle were that its accounts of nature's works were too "easily given in a few words," and too broadly applied to many distinct situations. These "uninstructive terms" prohibited deeper searches into the structure of nature and its mechanical operations. For example, Boyle wrote, to say merely that the eye is an organ of sight and that "this is performed by that faculty of the mind which from its function is called visive, will give man but a sorry account of the instruments and manner of vision itself."[68] Similarly, Boyle seems to have distinguished between two kinds of physicians. Those physicians who had not limited their understanding and explications of medicine to the simple and few qualities of the

[66] Harwood, "Science Writing," 51.
[67] Ibid., 51.
[68] *Christian Virtuoso, I, Works,* 5:516.

schools had "arrived at far greater attainments."[69] Meanwhile, certain other "dogmatical physicians" erred in rejecting "medicinal virtues" they thought not reducible to these scholastic qualities.[70]

To further enhance the clarity of his experiments' explications, Boyle occasionally used diagrams. For instance, Boyle, thinking that he alone might find the descriptions of certain experiments more intelligible by words alone than most men, consulted with others about which experiments in his *Continuation of New Experiments Physico-Mechanical* should be illustrated.[71] Among the skills belonging to the mathematician or the mechanist that improved natural philosophy were "lineal schemes, pictures, and instruments" that "much assist the imagination to conceive many things."[72] Since God "does geometrize in animals and plants," often the "greater dimensions" of a drawing can make clearer to the mind the "invisible contrivances" of nature.[73] According to John T. Harwood, Boyle painstakingly saw to the skillful layout of material on a page in order to enhance the reader's reception of its content. The illustrations that he used needed to be "lavish" enough for the reader's understanding of natural philosophy as well as the novice experimenter's successful reproduction of a trial.[74] Fittingly, one of Boyle's excuses for the lengthy duration between the publication of the first part and the

[69] *Specific Medicines, Works,* 5:78.
[70] Ibid., 78.
[71] *Spring, 1st Continuation, Works,* 3:178.
[72] *Usefulness, II, sect. 2, Works,* 3:441.
[73] Ibid., 441.
[74] Besides illustrations, Boyle utilized marginal references as important cues to the reader because, as Harwood writes, "no detail was too small to ignore": Harwood, "Science Writing," 46. Elsewhere, Harwood describes Robert Hooke's struggles with communicating new knowledge, including considerations of style, layout, and diagrams: John T. Harwood, "Rhetoric and Graphics in Micrographia," in *Robert Hooke: New Studies,* eds. Michael Hunter and Simon Schaffer (Woodbridge, England: Boydell Press, 1989), 119–147.

continuation of his air-pump experiments was that the "peculiar apparatus of instruments" required for the experiments could not "be intelligibly described without many words and divers figures."[75] The point of these practical efforts concerning the explication of his various experiments was to make them more intelligible to a variety of readers.

It would appear that there existed a touch of hypocrisy among Boyle's statements that apply to written communication. On the one hand, he strongly advised in favor of plain and simple phrasing free of ambiguous terms and rhetorical flourishes; on the other hand, his tracts clearly were full of many stylistic adornments, not least of which was the use of elaborate metaphors. But the incongruity did not escape his own notice, and he explained that he deliberately attempted to strike an effective balance between straightforwardness and grandeur. Perhaps fittingly, Boyle used an extended metaphor to make this point, as well. Yes, "where our design is only to inform readers, not to delight or persuade them, perspicuity ought to be esteemed at least one of the best qualifications of a style."[76] Yet "to affect needless rhetorical ornaments" in order to explain experiments is little less improper than "to paint the eye-glasses of a telescope, whose clearness is their commendation, and in which even the most delightful colours cannot so much please the eye, as they would hinder the sight" (304). But then Boyle disapproved also of "dull and insipid" writing. He declared that a philosopher should not concern himself with delighting his reader with "floridness," but he should take care not to disgust

[75] *Spring, 1st Continuation, Works,* 3:179.
[76] Boyle, "Considerations Touching Experimental Essays in General," *Certain Physiological Essays, Works,* 1:304. Page references in the text apply to this work until otherwise noted.

his reader “flatness” (305). “Discretion” should be taken to “adorn” rather than “darken.” Continuing the metaphor: “Thus (to resume our former comparison) though it were foolish to colour or enamel upon the glasses of the telescope, yet to gild or otherwise embellish the tubes of them, may render them more acceptable to the users, without at all lessening the clearness of the object to be looked at through them” (305).

This balance between sparseness and ornament applied to vocabulary as well. In his “Considerations Touching Experimental Essays,” Boyle further explained to Pyrophilus about the middle ground he sought for “exotic words” (305). Boyle hoped that anyone versed in more than moral, theological, or historical books would find that he makes use of “exotic terms” much less often than others. For his own tracts, Boyle claimed to have avoided using those that “custom has not rendered familiar,” unless to avoid tedious repetition of the same word (forbidden by orators), or unless the term provides an “energy” that cannot be expressed by a word in his own language (305). Sometimes, however, custom brought them into request. Again, an analogy to make the point clear: “For, as in the fashion of clothes, though perhaps fools begin them, yet wise men, when they are once generally received, scruple not to follow them, because then obstinately to decline them would be as ridiculously singular as at first it would have been to begin them: so in exotic words, when custom has once made them familiar and esteemed, scrupulously to decline the use of them may be as well a fault” (305). Again, here, the use of language involved the skillful and deliberate effort of the natural philosopher designed to ensure clarity of explications.

Under the topic of experimental contingencies I discussed the importance of complete disclosure of the circumstances surrounding individual experiments. Boyle thought this a significant communicative practice for a number of reasons. For one, he was concerned about the many unobvious contingencies that might effect the outcome of an experiment. Thus, understanding the many potential influences upon an experiment could account for discrepancies among results of different attempters of the same experiment. Also, the idea of extending witnesses to an experiment was significant to the business of the Royal Society and Boyle. Without mention of all the minute details, the experiment might not serve the naturalist who wished to include its results in his own narrative, nor could it properly serve the experimenter that desired to replicate the experiment for himself. Finally, complete disclosure was essential for warding off critics that could implicate some experimental sleight of hand and call into question the matters of facts derived from the trials. For these reasons the communication of experiments needed to be done skillfully and laboriously.

Along these lines is a connection that existed between promoting skillful communication of circumstances and the subject of credibility. Completeness of detail further served as absolution from contingencies that often led to what would appear an experimenter's failure. Boyle seems to have in mind a personal sore point as he explains in part two of "Two Essays Concerning the Unsuccessfulness of Experiments" that "wary and considerate naturalists" may be discouraged to find that their "faithfulness" in setting

down observations does not protect them from "blasting imputations of falsehood."[77] They expose their reputations to many uncertainties should their experiments later prove "obnoxious." He explained that if a writer were in the habit of delivering matters upon hearsay, and his experiments did not succeed upon trial, then it was fair to assign the error to the writer. On the other hand, if a writer was "wont to deliver things upon his own knowledge, and shows himself careful not to be deceived," it was "becoming both a Christian and a philosopher" to assume some "latent reason" why the experiment did not succeed (349). In short, if Boyle was "satisfied of the abilities and circumspection of a writer, delivering a matter of fact as upon his own knowledge" he would not reject an observation as untrue should some later discovery contradict it. For "sometimes there happen irregularities contrary to the usual course of things" (351). Thus, it was required for the "faithful relator of experiments" to divulge minute details of an experiment, as well as the sources of information for knowledge not directly observed.[78]

Just as having skills grounded in experimental natural philosophy could help the naturalist to properly perceive the many intricacies of God's creation, so too could this skillful knowledge improve communication. A frequent point throughout this study has been that Boyle relied on the skills and experience of craftsmen and tradesmen to help amass his collection of matters of fact about the natural world. Mobilizing their skill and experience, however, could enhance their credibility only in specific matters; they still lacked the proper communicative skills of the natural philosopher. Tradesmen

[77] "Two Essays Concerning the Unsuccessfulness of Experiments," in *Certain Physiological Essays, Works,* 1:349. Page references in the text apply to this work until otherwise noted.
[78] *Spring, Works,* 1:26.

themselves, no matter "so honest," did not know how to "describe in writing their own practices, and record the accidents they meet with"; so it behooved the natural philosopher to communicate phenomena from trades into the history of nature.[79] Part of the problem concerned secrecy. If a tradesman's livelihood depended in some way upon particular knowledge, he might not be forthright with protected details. Importantly, Boyle also claimed artisans may simply lack the "skill to deliver a relation intelligibly enough" and thus omit important circumstances due to over-familiarity or the presumption that certain details were already known by others. Sometimes this rendered their accounts "so dark and defective" that it made Boyle unsure of their truth until tested by himself or other artificers in different places.[80]

Boyle himself, however, recommended and practiced secrecy in certain communicative situations. Careful concealment was a social skill. We have seen the many avenues through which Boyle obtained knowledge. Many pertinent actors, especially certain tradesmen and chemists, did not wish their trade secrets made public, and so related information to Boyle on the condition of secrecy. In the description of certain mechanical experiments he withheld "some manual circumstances, because [he] was unwilling to prejudice some ingenious tradesmen" who made their livelihood through the use of such knowledge.[81] The "chymist's" secrets, too, needed protection. Among a list of experiments that Boyle recommended for his nephew "Pyrophilus" was one that Boyle did not teach him to make, for it would "break a promise" to keep quiet

[79] *Usefulness, II, sect. 2, Works,* 3:443.
[80] Ibid., 396.
[81] *Certain Physiological Essays, Works,* 1:315.

about an "odd salt" learned from a "traveller and a chemist."[82] Such discretion, he claimed, did not hinder his explications so long as the withheld details "were not necessary to the phisiological knowledge of the experiment; in naming which, [his] intention was to teach [Pyrophilus] rather philosophy than trades." Also, he withheld details about some of his methods so that he himself might have some "rarity" with which to barter among "those secretists, that will not part with one secret but in exchange for another."[83]

Much of the disparagement that Boyle reserved for scholastics and certain chemists concerned the incompleteness of their philosophical principles. But also important were his beliefs about the requisite skills that a philosopher needed for the proper study of nature and the communication of findings gained from it—skills that he found lacking in Peripatetic and chemical traditions. Because Boyle conceived of the universe as the intricate mechanical contrivance of a skillful and wise creator, his recommended approach to nature mobilized an artisan-like rhetoric. Proper natural philosophy necessitated work. Thus, he required multiple experimental trials to ensure the consistency of the matters of fact gained; he described the skillful perception of results that required a judicious use of the senses, reason, and knowledge; and he described adept philosophical communication, including skillful metaphors and effective style.

[82] *Forms and Qualities, Works,* 3:85.
[83] *Certain Physiological Essays, Works,* 1:315.

CONCLUSION

Skill, Experience, and the History of Science

Before we can hope to understand seventeenth-century British science, we must put away simple categories such as external and internal. Such concepts may help to describe the scholarship that addresses the Scientific Revolution, but the task of maintaining a one-sided explanation that either exclusively asserts social, political, and religious influences or isolates intellectual tradition and inspiration proves hopeless. This examination of the importance of the personal qualities of skill and experience to the English natural philosopher Robert Boyle demonstrates the difficulty of simple categorization.

Scholars of the Scientific Revolution in Europe have always paid generous attention to England. John Henry traces England's role in the philosophical explanations about the driving forces behind seventeenth-century science.[1] During the 1930s, interpretations such as Boris Hessen's Marxist assertions and Robert Merton's Weberian thesis both used England as the primary stage. Whereas Merton agreed with Hessen's presentation of economic and military influences on English scientific development, he added his own emphasis for capitalism in a Puritan context. Henry describes some of the flaws in Merton's Puritan emphasis, which relate to usefully defining Puritanism and identifying who should fairly be labeled a Puritan. Charles Webster's attempts at extending and remedying Merton's thesis by emphasizing the millennial idea of progress

reveals other shortcomings. Not the least of these, claims Henry, is a failure to explain "why and how a recognizably 'modern' science" flourished in Interregnum England, and its failure to help us understand the thought of individuals such as Boyle, Newton, and others that were prototypical of subsequent science.[2] As Henry wisely points out, it is one thing to "provide a motive and a sanction for experimentalism, and it is another to show how particular experiments were devised and conducted, and how their conclusions were received."[3]

It is at this juncture—where the internal considerations meet the external context—that I wish for this study to be understood. I do not desire to explain *why* English science developed a more experimental composition than did continental science, but rather *how* Robert Boyle confronted the daily technical problems of doing experimental natural philosophy and communicating its information to other virtuosi and society. As we have seen, on the one hand, the human characteristics of skill and experience emerged as very technical and practical considerations for Boyle as he assessed the credibility of testimony for his natural histories and in his execution of particular experiments that involved the participation of others. On the other hand, one cannot escape the social implications that resulted. For instance, Boyle's statements sometimes belied a conflict when he advanced the skillful and experienced testimony of artisans, who lacked education. The inconveniences accompanying the contingencies associated with lacking human skills did bear upon his pursuit of experiment in a very

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[1] Henry, "Scientific Revolution in England," 178–182.
[2] Ibid., 179–180.
[3] Ibid., 180.

practical and technical way. Yet such problems appear even more charged when considered in the context of seventeenth-century society and their potential for jeopardizing the acceptance of the experimental method. Further, societal attitudes definitely influenced the manner in which he conscientiously approached manual skill when recommending experiment to his gentlemanly readership. Yet he was clearly operating within the conglomerate of intellectual traditions still current in seventeenth-century England as he asserted the various practical intellectual skills that the experimental natural philosopher should possess.

Boyle's sensitivity to the varying levels of skill and experience among witnesses, writers, experimenters, artisans, and his readers comprises a significant theme throughout much of his prolific writing about experimental science. Not surprisingly, these concepts had great relevance to natural philosophy during the late seventeenth century. The brand of experimental philosophy that Boyle and other Fellows espoused involved work, and thus, as in the trades, they were forced to contend with human skill and experience. I hope that greater awareness of these concepts significantly broadens and enhances understanding about this important nascent period of English experimental science and advances a more complete picture for Boylean studies.

The Last Word: Boyle and the Skillful Future

Clearly, Boyle perceived a hopeful future for natural experimental philosophy. True, statements that portrayed the era in which he himself lived as the new age of right-minded mechanical-experimental philosophy abound in his work. As discussed, Boyle decried that the Peripatetics had demonstrated little practical skill in the production of

knowledge. The "modern" virtuosi, on the other hand, manipulated nature in experimental trials in order to force the proper rendering of copious matters of fact. But I do not believe that he perceived himself to be living in a true and final "golden age" of science. Having witnessed for himself the advances in natural philosophy that were built upon experimental skills and innovative instruments, he conceived of a future for science that would be even more productive than his advanced present. Boyle explained to Pyrophilus that the young gentleman should not think it strange that "the usefulness, for which I would recommend physicks, suppose future proficiency in them, if you consider the nature of my design; which is not to make an elogium of natural philosophy, imperfect as it yet is, but to show, that as it may be, and probably will be, improved, it may afford considerable advantages to mankind."[4]

Boyle's apprehension for building grand theories—"superstructures"—while certainly a commentary on his times and the style of philosophy of which he disapproved, was also but a part of his hope for science's future. His reluctance represented a merely temporary restraint.[5] The building of grand theories was not philosophically illicit, per se, but rather unwise barring a complete foundation of experimental facts—which the future would provide. Writing about his "doctrine" describing the spring and weight of the air, Boyle defended that his "chief design" was not to establish theories, "but to devise experiments, and to enrich the history of nature with observations faithfully made and delivered; that by these and the like contributions made by others, men may in time be

[4] *Usefulness, II, sect. 2, Works,* 3:422.
[5] Of course, it is worth noting that Boyle did not refrain entirely from theorizing in his philosophical writing, in spite of recommending against it.

furnished with a sufficient stock of experiments, to ground hypotheses and theories on."[6] Boyle resumed this notion of the humble "under-builder" elsewhere. He claimed contentment with contributing in any helpful way to the advancement of natural philosophy. His humility seemingly knew no bounds when writing that he would be satisfied to "not only be an under-builder, but even dig in the quarries for materials for so useful a structure, as a solid body of natural philosophy, than not do something toward the erection of it."[7] This last example clearly implied the vast amount of work that Boyle perceived would follow him.

Experimental skill and skillful production of instrumentation would continue to render the invisible, visible. The contingencies that altered experimental expectations, for example, might no longer baffle the experimenters of the future. Many "contingent experiments, which to us yet seem to belong to the first sort [the indiscernible], by men's future skill and diligence in observation, may be made fit to be reduced to the second sort [the discoverable]."[8] During Boyle's day, physicians and philosophers debated the efficaciousness of "occult" properties and "specific virtues" of medicines. Within the context of arguing for mechanical explanations of perceived phenomena, Boyle asserted that the future would put to rest qualitative speculation: "In time the industry and sagacity of men will be able to discover [unknown] causes of most of those qualities, that now pass for occult, and among them of many of the specific virtues ascribed to medicines."[9]

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[6] *Defence, Works,* 1:121. Similarly, Boyle "would have such kind of superstructures looked upon only as temporary ones . . . or, if you please, the best in their kind as we yet have": *Certain Physiological Essays, Works,* 1:303.
[7] *Certain Physiological Essays, Works,* 1:307.
[8] Ibid., 342.
[9] *Specific Medicines, Works,* 5:78.

The advancements owing to the production of scientific instruments, too, would reveal truths as yet unseen. Besides the discovery of recently unknown orbs in the night sky, "our better tubes" have also revealed multitudes of "fixed stars" unknown to the ancients. There is little doubt, continued Boyle, that "if our glasses should be further improved, there will be still more and more numerous stars detected."[10] As telescopes become "more and more improved, so we discover more and more stars in what we call the firmament; it will be difficult for us men to know, to what extent the vastness of the universe may not reach" (721). In the same tract, Boyle wrote that the study of nature was useful to increase knowledge of natural things, "if not immediately, and presently, yet in time, and in the issues of affairs" (776).

His religiosity ever connected to his natural philosophy, Boyle wrote of enlightenment in the ultimate future as a combination of knowledge gained through natural philosophy and rewards provided by God. In the "future state of things" corporeal creatures that will then be known "shall probably be known best by those, that have here made the best use of their former knowledge . . . together with their other gifts. . . . And then the attainment of a high degree of knowledge, which here, was so difficult, may to the enlightened and enlarged mind, become as *easy*, as it will be *satisfactory*" (776, emphasis his). What is yet more fascinating is how importantly the concepts of skill and dexterity figured into his analogies for this "future state." Mankind, asserted Boyle, was presently in as comparative a state of "weakness and ignorance" as a wild native "that has never used his hands, but about the most familiar and simple works" (777). He can have

[10] *Christian Virtuoso, II, Works,* 6:720. Page references in the text apply to this work until otherwise noted.

no idea of the exquisite work “that the hands of an excellent architect, a dextrous mechanist, a curious painter, and a skillful musician, may be taught to produce” (777).

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